Evaluation of Occupational Noise Exposure – Advantages and Disadvantages of Noise Dosimetry versus Sampling Using a Sound Level Meter

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ABSTRACT

There are two methods for evaluating noise exposure in the workplace: dosimetry using a Personal Sound Exposure Meter (PSEM) and sampling using a sound level meter (SLM). This paper discusses the advantages and disadvantages of both methods in the context of the fundamental objectives of an occupational noise survey, i.e. identification of exposed workers, determination of exposure magnitude, and identification of the noise sources, processes and activities that contribute to exposure. Exposure evaluation using a sound level meter is quick and reliable when noise levels are relatively low and when exposure varies little as a function of time. When noise levels are very high, however, even very small changes in assumed exposure duration can have a significant effect on the calculated exposure. On the other hand, dosimetry avoids having to estimate exposure durations but can take much longer to assess an entire workforce. These aspects, as well as equipment and measurement considerations are discussed and it is concluded that a well designed measurement strategy is likely to incorporate both methods.

INTRODUCTION

Occupational noise surveys are a key step in managing noise in workplaces and ultimately reducing the noise exposure and noise-induced hearing loss of the workforce. Accurate assessment of noise levels and noise exposures is crucial in the fight against NIHL, and there are two principal tools used on site by noise assessors – the integrating-averaging sound level meter (SLM) and the personal sound exposure meter or noise dose meter (PSEM). Both types of instrument have been used in workplaces around the world for many years. In the hands of a skilled and competent noise assessor, both types of instrument will give useful and practical information about the noise levels in a workplace, but it has been found that both instruments do have shortcomings when making accurate assessments of noise exposure.

Australia/New Zealand Standard AS/NZS1269:2005 Occupational Noise Management - Part 1: Measurement and Assessment of Noise Immission and Exposure(1) states that “Hand held sound level meter measurements made by competent people are preferred to measurements using PSEMs” due to what are described as the “confounding effects” of PSEMs.

This paper discusses the benefits and shortcomings of both types of instrument, including these so-called confounding effects, in relation to the fundamental objectives of an occupational noise survey.

NOISE SURVEYS

According to AS/NZS1269.1:2005, the general objectives of a noise assessment are

(a) To determine the exposure to noise of all people likely to be exposed to excessive noise.

(b) To obtain more specific information that will help decide what measures to take to reduce noise.

(c) To check the effectiveness of any control measures which have been applied.

(d) To assist in the selection of appropriate hearing protectors where other control measures are not practicable, or will take some time to plan and implement.

The exposure to noise referred to in item (a) is established in terms of the eight-hour equivalent continuous A-weighted sound pressure level ($L_{Aeq,8h}$) or A-weighted noise exposure ($E_{A,T}$), and the peak sound pressure level (L_{peak}) (1).

Once these results are known, then appropriate steps can be taken to reduce the exposure of personnel using a variety of strategies.

Since this paper is concerned only with the practicalities of noise exposure assessment, it does not consider the details or effectiveness of these strategies, or the use of hearing protectors, but focuses on the various practical methods by which $L_{Aeq,8h}$ and L_{peak} results are derived.

NOISE EXPOSURE

Modern SLMs and PSEMs can measure both $L_{Aeq,T}$ (the equivalent continuous A-weighted sound pressure level over a given measurement time T) and L_{peak}, directly.

$L_{Aeq,8h}$, by contrast, must usually be calculated. To do this, the various measured $L_{Aeq,T}$ values and an accurate assessment of the exposure duration are required.

These can be obtained in two ways – by sampling using a SLM to measure representative values of $L_{Aeq,T}$ then combining this information with estimates of the actual duration of exposure to each of the sampled levels, or by using a PSEM.

Since a PSEM is designed to be worn by a worker for his or her entire workshift then the duration is accounted for simply by wearing the PSEM continuously throughout the shift.

Contrast this with the use of a SLM which necessarily requires the presence of a competent noise assessor, who will typically take a representative reading of sound pressure level as an $L_{Aeq,T}$ then ask questions of the operator, supervisory staff, other operators, management and other appropriate personnel to get estimates of the time spent in each location or at each task throughout the shift.

USING A SOUND LEVEL METER

When carrying out an occupational noise assessment using a SLM, the noise assessor makes a measurement or series of measurements of sound pressure level (usually as a short-term $L_{Aeq,T}$), ideally ensuring that each measurement is truly representative of the particular noise environment under consideration. To ensure this is the case, the assessor needs to speak in detail to the operator and any other appropriate personnel to determine the nature of the noise, its characteristics, any variations, typical and atypical situations, frequency of repetition if the noise is cyclic or repetitive, and so on. Once this has been established, then the duration of measurement can be decided by the assessor.

For occupations or tasks which have noise climates where the level varies little throughout the shift (for example, haul truck drivers) then gauging a suitable assessment period is a relatively straightforward task. Even a short measurement of only a few minutes may be deemed representative of the entire shift.

For shift patterns where the noise climate changes appreciably throughout the shift, choosing representative assessment periods is considerably more difficult, and the noise assessor may need to make a number of discrete measurements, each of which must be representative of a particular task, area or process, then combine the measurements into an overall exposure calculation. Alternatively, the assessor can choose a much longer measurement duration and effectively follow the worker as he goes about his duties. This is clearly less practical than taking a series of shorter measurements, but would in most cases result in a more accurate overall figure of noise exposure.

This is because by taking short representative samples of noise levels at a worker's ear from different tasks, the noise assessor is then reliant on information about how long each worker is exposed to each level of sound throughout the day in order to calculate the total exposure $L_{Aeq,8h}$.

Obtaining accurate information about exposure durations is the largest source of error when calculating $L_{Aeq,8h}$ from SLM measurements.

Continuous low level noise

Consider a situation where a worker spends the whole of his 12 hour shift driving a haul truck up and down an incline at a mine. If the noise assessor measures the level at the driver's ear when the laden truck is ascending the incline, and again when the truck is descending unladen back into the mine, then he will have obtained a representative sample of the noise levels the driver is exposed to throughout the day, since the task does not change and the assessor has dealt with the two main noise environments within the shift – ascending and descending.

Combining this information with knowledge of the driver's shift length, and the duration and frequency of any breaks during the shift, then it is reasonable to assume that even quite short measurement periods will be representative of the entire shift. In this case, the calculation of $L_{Aeq,8h}$ from the results from the SLM and information about shift length will give an accurate result for that worker's noise exposure.

Example:

A truck driver is exposed to an $L_{Aeq,T}$ of 90 dB(A) when ascending the incline with a laden truck, and to 85 dB(A) when descending unladen. He works for 11 hours of a 12 hour shift, the remaining hour being taken as breaks in a quiet area (where the noise level is assumed to be low enough to be insignificant in the calculation of noise exposure).

Assuming half of his working hours are spent ascending and half are spent descending, then the $L_{Aeq,8h}$ is calculated from equation (1) below.

$$L_{Aeq,8h} = 10\mathrm{Log}_{10}[(t_1 x 10^{L1/10} + t_2 x 10^{L2/10})/8] \quad (1)$$

where t_1 is the time spent exposed to a level of L1 dB(A) and t_2 is the time spent exposed to a level of L2 dB(A).

In this case,

$$L_{Aeq,8h} = 10\mathrm{Log}_{10}[(5.5 x 10^{90/10} + 5.5 x 10^{85/10})/8]$$

$$L_{Aeq,8h} = 89.6 \text{ dB(A)}$$

The exposure time ascending and descending can be readily and accurately assessed by observation. Since the level at the operator's ear can also be assumed reasonably constant during the ascent and again during the descent, then this result for the daily exposure can be said to be correct with a good degree of certainty. Even with a short measurement period of, for example, 15 minutes during the ascent and descent, this value for $L_{Aeq,8h}$ would normally be considered accurate.

Frequently varying or high level noise

Now consider the case where an operator works in a maintenance workshop, using a variety of air and electric tools. It is highly likely that noise levels from each of the different items of equipment being used will be quite different. It is also likely that the operator will use each piece of equipment for different lengths of time from day to day.

This introduces two problems: First, how long must the noise assessor measure each item of equipment for to get a representative sample, and second, how long each day does the operator actually use each item of equipment?

From equation (1), it can be seen that the calculated exposure is based on just two parameters – the noise level at the operator's ear when performing a particular task, and the length of time that task is performed. For multiple tasks, equation (1) is simply extended to account for all tasks and noise levels associated with them, resulting in a potentially large number of t and L terms.

Thus the accuracy of the level measured and of the exposure time estimated becomes critical. Furthermore, the higher the measured level, the more critical the assessment of actual exposure time becomes.

Example:

A maintenance engineer works a 10 hour shift, and spends 9 of those hours in a workshop operating various tools and items of equipment. He estimates that he spends 1 hour per shift operating a grinding wheel, 2 hours per shift operating a drop-saw, 3 hours per shift operating a rattle gun, 2.5 hours operating a pillar drill, and half an hour using welding equipment.

The noise assessor must make accurate, representative measurements of the noise level due to each of these items, and must also rely on the information given by the worker about how long each piece of equipment is used.

Let us assume that representative measurements have been made when the operator is using each of the above items and the noise assessor has found the following $L_{Aeq,T}$ levels:

Grinding wheel: 92 dB(A); Drop-saw: 88 dB(A); Rattle-gun: 99 dB(A); Pillar drill: 85 dB(A); Welding: 96 dB(A).

Using equation (1) to calculate the $L_{Aeq,8h}$ from the information given above:

$L_{Aeq,8h} = 10Log_{10}[(1x10^{9.2} + 2x10^{8.8} + 3x10^{9.9} + 2.5x10^{8.5} + 0.5x10^{9.6})/8]$

$L_{Aeq,8h} = 95.7$ dB(A)

However, it is quite possible that the estimates of exposure duration may be some minutes different to the actual exposure time on any given day.

The effect of this can be very significant on the overall exposure. If for example the length of time spent using the rattle gun was actually 3.5 hours rather than the estimated three, the $L_{Aeq,8h}$ then becomes 96.2 dB(A).

Similarly, if the measured level was found to be 99 dB(A) using the rattle gun on one particular day, but was 101 dB(A) on another occasion due to different settings, then the $L_{Aeq,8h}$ (assuming the original 3 hour duration) on this second occasion would be 97.3 dB(A).

These apparently small variations in $L_{Aeq,8h}$ equate to significant changes in daily exposure. An increase of only 3dB in $L_{Aeq,8h}$ effectively requires a halving of overall daily exposure time to maintain the same daily exposure level.

If this rather oversimplified scenario is substituted for a real situation where there are many more tools and tasks during the day, and the level and duration of each task varies from day to day, it can be seen that using a sound level meter for sampling levels at the operator's ear and using estimates of actual exposure time to calculate the daily exposure can be prone to significant errors.

USING A PERSONAL SOUND EXPOSURE METER (PSEM)

A personal sound exposure meter (PSEM) is designed specifically to be worn by a worker for the duration of his or her workshift, obviating the need for a noise assessor to follow the worker around making representative measurements for each of the different tasks or areas that the worker is involved in.

If the PSEM is worn for the entire shift, one significant potential source of error in $L_{Aeq,8h}$ calculation is immediately eliminated – the duration of exposure to each task is automatically accounted for, and so estimates - frequently inaccurate - are no longer required.

Additionally, since the PSEM is worn for the entire shift and therefore the full length of each task within that shift, then any variations in noise level during that time are again accounted for, without relying on a noise assessor to estimate what is a representative measurement period. In the examples above, a PSEM would be equally practical in both cases and would, in the case of the multiple tools in the workshop, make the measurement much easier and in theory more accurate, since all variations in sound level and exposure duration are automatically accounted for by the meter.

Therefore, the PSEM would appear to be the preferred method for assessing daily exposure, since it is not prone to errors in the subjective representative measurement of $L_{Aeq,T}$ nor in erroneous duration estimates, the two key aspects of exposure.

Fitting a PSEM to a worker for the entire duration of their shift should therefore produce the most accurate results for the $L_{Aeq,8h}$.

However, there are a number of factors to be considered when using PSEMs as a method of assessing daily noise exposure.

In many instances, PSEMs are not worn for the entire shift and for logistical reasons may be worn for only part - often less than half - of a complete shift. This is not a serious concern where the average noise level for the remaining shift time is the same as it was for the measured part of the shift. In the case of long-term continuous tasks, like the haul truck driver in the earlier example, then assessing a partial shift with a PSEM is usually acceptable since the noise level changes very little throughout the shift, providing the appropriate calculations are made to obtain $L_{Aeq,8h}$. However, where noise levels may change significantly throughout the working day, then full-shift monitoring is really the only way to get an accurate measure of the exposure. If a PSEM is worn for only part of the shift, then one of the key advantages of a PSEM over a SLM is lost – that is, the assessment of actual noise levels over the actual total exposure duration. Removing a PSEM before the completion of the shift introduces some of the same assumptions about noise characteristics and exposure duration which have already been shown to potentially cause significant errors in noise exposure calculations using a sound level meter for sampling.

However, even if a PSEM is worn for the entire shift, a number of other factors need to be considered before the results are taken at face value.

"Confounding Effects"

Since the purpose of a PSEM is to be worn by the worker without the permanent presence of a competent noise assessor, it is impossible to trace the history of what has happened to the PSEM during the measurement period. It is not uncommon for the worker to interfere – accidentally or deliberately – with the measurement. This can be caused by touching the microphone, operating the switches, blowing, whistling or shouting into the microphone, accidentally knocking the microphone, or even removing the PSEM altogether and replacing it before the noise assessor is due to collect it.

Most manufacturers of PSEMs have made some attempt to minimise aspects of these "confounding effects"[(1)], by providing lockable keypads, protective covers and so on, but of course there are limitations to the effectiveness of such measures.

Logging PSEMs are able to record sound levels (typically $L_{Aeq,T}$ and L_{peak}) at preset intervals, typically once per second or once per minute throughout the measurement period. This allows the noise assessor to correlate daily activity with recorded noise levels, and can help to pinpoint areas where the PSEM may have been interfered with, but this is of course not always 100% reliable.

Another area of concern is the location and orientation of the PSEM microphone. Ideally, the microphone should be placed close to the operator's ear, pointing towards the noise source, at the ear receiving the highest noise level (in order to assess the worst-case scenario). Clearly it is not always possible to ensure this is the case, particularly if the operator is moving from task to task or area to area. In reality, PSEM microphones are usually attached to the lapel or shoulder of the worker, pointing forwards or downwards, which in most cases is appropriate, but for particularly high frequency noise or noise containing high frequency tones, then the orientation of the microphone becomes quite important. An incorrectly orientated or positioned microphone can introduce significant errors into the measured levels when the noise is primarily high frequency.

Peak Level, L_{peak}

Of major concern to those using PSEMs for occupational noise assessments is the measurement of peak level, L_{peak}.

L_{peak} is a measure of the maximum instantaneous sound pressure displacement, usually of very short duration and high level, which has the potential to damage hearing instantly.

Authorities in Western Australia and indeed around the world currently use a Peak Action Level, or Peak Exposure Standard, of 140dB. In some cases, this is C-weighted, in others the Linear (Z-weighting) is used (2)(3). In either case, the implication is that peak levels above 140dB can be harmful to hearing, possibly instantly.

Therefore it is clear that accurate measurement of peak sound levels is critical to the issue of hearing conservation.

Using a SLM, the peak level can be accurately measured by the competent noise assessor at the same time as witnessing the source of noise which may be causing high peak levels. This way, the assessor can be confident that what he or she is measuring on the SLM is indeed a genuine peak level.

In the case of a PSEM, however, not only will the noise assessor not be present, but it is quite possible to create artificial peaks of over 140dB by tapping, knocking or even brushing the microphone, accidentally or otherwise. This is because, even though PSEM microphones are ruggedised, their design means that any movement of the diaphragm is interpreted as noise, even if the movement is induced mechanically rather than by air movement associated with sound. (SLM microphones have the same issue, but it assumed that SLMs will be used by trained noise assessors and therefore the microphones will be treated appropriately). Even logging PSEMs cannot distinguish between a genuine peak level of >140dB and a similar level caused by physical interference with the microphone.

Anecdotal evidence suggests that this phenomenon is quite common and affects PSEMs of any make or model to some degree. Thus peak levels measured using a PSEM should be treated with some caution, until follow-up measurements can be made with a competent noise assessor present, using a suitable SLM to verify the PSEM results.

Indeed, for detailed noise assessments, AS/NZS1269:2005 requires the use of a Class 1 / Type 1 instrument when assessing peak levels, and since most PSEMs satisfy only the requirements for a Class 2 / Type 2 sound level meter, then a SLM will often be required to measure peak noise levels anyway. (That said, not all authorities call on the requirements of this Standard for noise assessments, and in some cases a Class 2 / Type 2 SLM/PSEM is sufficient).

The issue of misleading peak level results, along with the practical issues of PSEM use by unsupervised, often untrained personnel, together described as "confounding effects" in AS/NZS1269:2005, are the reason that the standard states "Hand held sound level meter measurements made by competent people are preferred to measurements using PSEM."

However, there are a number of other advantages and disadvantages of both SLMs and PSEMs when assessing occupational noise exposure.

SLMS VS. PSEMS

As has been shown, both sound level meters and personal sound exposure meters are widely used in the assessment of occupational noise exposure. The key factors in both cases have been described above. However there are several pros and cons to be considered in addition to these, affecting the practical use of the instruments and the theoretical calculation of the results.

When using a SLM, a skilled, trained and competent noise assessor is required for 100% of the measurement time. A considerable amount of time is also required for the noise assessor to follow up the measurements with numerous questions and sometimes lengthy discussion with operators, supervisors and managers in order to adequately characterise the tasks, shift patterns, noise characteristics and exposure durations for each worker or group of workers.

However, using a SLM, an experienced noise assessor should be able to gather noise measurement results from a large number of workers in a relatively short time by making appropriate measurements over representative periods.

As we have seen though, the accuracy of exposure results obtained using a combination of SLM measurements and duration information provided by workers is prone to significant errors. This is because even small errors in measured level or estimated duration can result in appreciable variations in $L_{Aeq,8h}$.

Once a PSEM has been calibrated, set up, and fitted to the worker at the start of the shift, then no further noise assessor interaction is required until the PSEM has to be removed and the results assessed. However it is probable that some time will still be required for discussion of shift patterns, task descriptions and so forth to make the best use of the collated data, particularly if the PSEM has a logging capability.

Additionally, when using PSEMs, it can take a significant amount of time to gather similar information as an SLM, since it is likely that only a small number of PSEMs might be available and clearly when monitoring an individual for an entire shift to get one result, it is a time-consuming process to cover all workers or groups of workers.

However PSEMs get around the significant problem of representative levels and estimated exposure times by measuring for the entire shift, and measuring the actual noise levels for that shift, thereby dispensing with the need for approximations and estimates.

As we have also seen, however, the very fact that PSEM measurements are unattended by the noise assessor leaves room for other factors to affect the outcome, in particular, interference (deliberate or otherwise) from the wearer.

Furthermore, when using a SLM, the presence of the noise assessor means that he or she has first-hand experience of the noise characteristics being measured. In addition to complex and expensive instruments, a noise assessor will use his or her ears to assist in the assessment, particularly for determining appropriate measurement durations and whether a measurement can be considered representative of the task at hand or not. The presence of the assessor can also help considerably in identifying noise sources and those workers affected by them.

The use of PSEMs cannot of course provide this same level of assessor interaction, but can provide larger amounts of logged data over longer periods of time than are available to a noise assessor using a SLM alone, assisting in the identification of noise sources having the most significant contributions to the total exposure.

Further, from a practical point of view, it is not always easy to use a SLM, for example to assess the exposure of a driver in a single-seat cab, or a boilermaker inside a confined space. Therefore a PSEM would usually have to be used.

More generally, a PSEM is the ideal tool for continuous long-term monitoring programs, where results may be reviewed periodically (eg annually) to assess any changes in long-term exposure patterns of individual workers or work groups. Additionally, a PSEM makes no assumptions about what is significant and what is not – everything is measured during the monitoring period and it is then the trained noise assessor's job to determine the significance of the different jobs, tasks, noise characteristics and so forth. Using a SLM and asking an acoustically untrained operator for information about their exposure is prone to subjective responses regarding what they consider to be significant, so important sources of exposure may be missed.

Assessing noise exposure using a SLM provides a snapshot of the noise climate at a particular time, typically once every 5 years during a noise survey, and the results are dependent on the noise on that particular day, whereas a PSEM can provide a broader picture when used as part of an ongoing monitoring program, highlighting variations over a much longer period of time.

At the same time however, it is usually impractical to collate PSEM data for a sufficiently large sample of the workforce only during the 5-yearly noise survey due to time and resource constraints. Here, the SLM is the more practical tool.

So it can be seen that to provide a complete picture of the total noise climate in a workplace, both periodic noise surveys and ongoing noise monitoring are required. To facilitate both of these, SLMs and PSEMs should be used in combination to cover as many scenarios as possible.

CONCLUSION

The two principal tools in the assessment of occupational noise exposure are the Sound Level Meter and the Personal Sound Exposure Meter. Both of these instruments typically measure $L_{Aeq,T}$ and L_{peak}, which form the basis of noise exposure calculations. The $L_{Aeq,T}$ or a series of $L_{Aeq,T}$ results are converted to $L_{Aeq,8h}$ based on a knowledge of exposure duration, shift length and work patterns.

When using SLMs, small inaccuracies in measured levels or estimated exposure time can have significant effects on the resulting daily noise exposure level, $L_{Aeq,8h}$, particularly when noise levels are high. They are however useful for gathering large amounts of information quickly, and in the hands of a skilled noise assessor, the results are usually reliable.

While PSEMs obviate the need for these various approximations and estimates, they do have their own inherent inaccuracies due to the manner in which they are used in practice. They do however provide a longer-term monitoring option for which a SLM would be impractical. A PSEM can provide information which would otherwise be missed using only a SLM, and is the more useful tool for assessing noise climate changes over time. Again an experienced noise assessor can examine and interpret the results with a good degree of confidence.

It has been demonstrated in this paper that both SLMs and PSEMs can be appropriate, practical tools to assist in accurate occupational noise assessments, and neither is unequivocally more suitable than the other. In a well-conceived noise management program, there is a place for both sound level meters and personal sound exposure meters for occupational noise assessments, and the most accurate and comprehensive results – and therefore the most appropriate and effective noise reduction measures – are achieved when using a combination of both sound level meters and personal sound exposure meters.

REFERENCES

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