Sound power assessment on earth-moving equipment

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ABSTRACT

Sound power level is a measure of the total noise emission from operating equipment and a useful information for equipment manufacturers, buyers, installers and acousticians. *In-site* determination of sound power levels of operating equipment is normal practice in many consulting projects. In this paper, *in-situ* measurement of sound power levels of earth-moving equipment is of concern. Results presented are typical and selected from the SVT database collected for different consulting projects. Results indicate that the 4-point method gives similar results as the ISO method but it has the advantage of time and cost effective, and easy to implement in practice. The MDG-15 method gives lower values compared with the 4-point method. Noise emission from equipment under dynamic (drive-by) conditions is lower than under stationary (high idle) conditions, and could be affected by loading or road conditions. For environmental modelling, it is suggested that the sound power levels input to noise models for mobile equipment should be measured under drive-by conditions rather than under high-idle conditions.

INTRODUCTION

Sound power level is a measure of the total noise emission from operating equipment and used in:

- comparing the noise output from different equipment,
- evaluating the effectiveness of noise control measures on the same equipment,
- rating (labelling) noise output of equipment, and
- quantifying noise sources for environmental assessment on the proposed operations such as mining or constructions.

Different measurement methods have been proposed and some of them have been standardized [1,2]. The accuracy of a measurement method is always of concern. For acoustic consultants, however, feasibility, time and cost effectiveness also needs to be considered.

SVT has undertaken many *in-situ* sound power measurements of earth-moving equipment during the consulting services. This paper presents the typical results selected from the SVT database. It is not the intention of the author to disqualify one method from another. The aim of this paper is to share SVT experience and to attract the attentions from academic researchers and acoustic consultants to work on accurate, time-effective and practical methods for *in-situ* determining sound power levels of earth-moving equipment under different operation conditions.

MEASUREMENT OF SOUND POWER LEVELS

The A-weighted sound power level, L_{WA}, in dB(A) can be calculated using the following equation (ISO 6393:2008)(ISO 6395:2008):

$$L_{WA} = (L_{pAeq,T} - K) + 10\log10(S/S_0) \qquad (1)$$

where $L_{pAeq,T}$ is the equivalent continuous A-weighted sound pressure level averaged over the measurement surface, K is the environmental correction factor in decibels, S is the area of measurement surface and S_0=1 m^2. The correction factor K is normally negligible for field measurements.

The accuracy for the estimation of sound power levels depends on the accuracy of measurement on $L_{pAeq,T}$. Several methods are available for the measurement of $L_{pAeq,T}$.

ISO 6393

ISO 6393 details the test code for measuring $L_{pAeq,T}$ on earth-moving equipment under stationary conditions. Six measurement positions are specified as shown in Figure 1. R is the radius of the measurement surface (hemisphere) and it depends on the size of tested equipment.

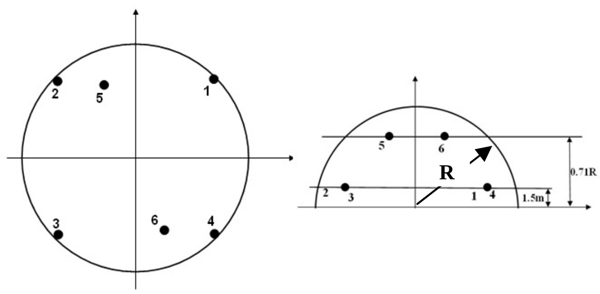

Figure 1. Microphone array on the measurement surface (hemisphere).

4-Point Method

Positions 5 and 6 are more than 11m above the ground for most earth-moving equipment. It is not possible for using a pole to locate microphones at these two positions. Measurements at positions 5 and 6 require lifters such as cherry-pickers. To make the measurements time and cost-effective and easy to implement under field conditions, SVT has studied the level difference (error) if data at positions 5 and 6 are excluded from the calculations of $L_{pAeq,T}$. Results indicated that the calculated $L_{pAeq,T}$ using the data obtained at positions 1 to 4 (4-point measurements) is usually lower than that calculated using the data obtained at positions 1 to 6. However, the overall level difference is less than its 95% standard deviation for most cases.

MDG-15

Another measurement method (described in a document supplied by BHP Billiton for one of SVT consulting projects) was proposed for measuring $L_{pAeq,T}$ on earth-moving equipment under stationary conditions by BHP at Hunter Valley Coal. This method involves the following steps:

- Locate the acoustic centre for the operating earth-moving equipment.
- Mark a measurement circle centred at the acoustic centre with the radius of R=L+H/2 where L is the length of the tested equipment and H is the height.
- Set the microphone to be half the height of the tested equipment or 4m whichever is smaller.
- Record the equivalent continuous sound pressure levels by walking along the marked circle (twice) in clockwise and anti-clockwise directions.

Drive-by Test

ISO 6395 details the test code for measuring $L_{pAeq,T}$ on earth-moving equipment under dynamic conditions. This measurement method requires (simultaneous) recording of six signals at six locations, as shown in Figure 1. This method is very difficult to implement in the field conditions. To make the measurements time and cost-effective and easy to implement under field conditions, SVT has developed a simpler procedure for measuring $L_{pAeq,T}$ at two locations, as shown in Figure 2 where A and B are the microphone locations. The distance droved during recording period should be greater than 20m. R is calculated in the same rules as in Figure 1 (ISO 6393:2008)(ISO 6395:2008).

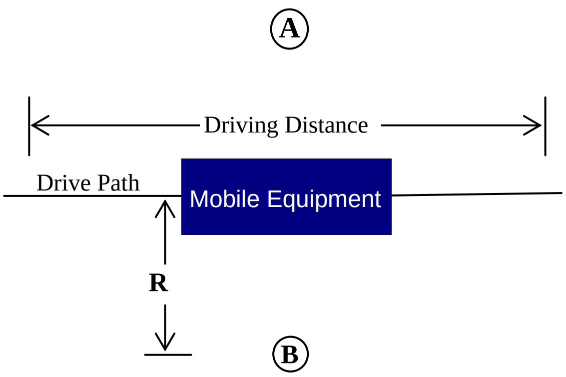

Figure 2. Microphone locations for drive-by tests.

MEASUREMENT RESULTS

The results presented in the following figures are the average over 3 sets of recording data, ie. 3 measurements were taken at each location, except for MDG-15 which requires two measurements (in clockwise and anti-clockwise directions) only. Sound Level Meters were calibrated before and after the measurements. Correction of background noise has been made for each measurement data. The correction factor is neglected (K=0) in the calculations.

Figure 3 shows the sound power levels measured on the same equipment under stationary (high idle) conditions using the ISO6393 (6-points) method and the 4-point method respectively. Figure 4 shows the level difference between the two results in Figure 3 and the 95% standard deviation of the results measured using the 4-point method. It is shown that the ISO6393 method gives a similar spectrum shape but slightly higher value than the 4-point method at frequencies above 250Hz and with an overall (A-weighted) level difference of 0.8 dB(A). The level difference between two measured values is smaller than the 95% standard deviation at all frequencies. This indicates that the results measured by the ISO6393 (6-points) method fall inside the 95% confidence interval of the results obtained by the 4-point method.

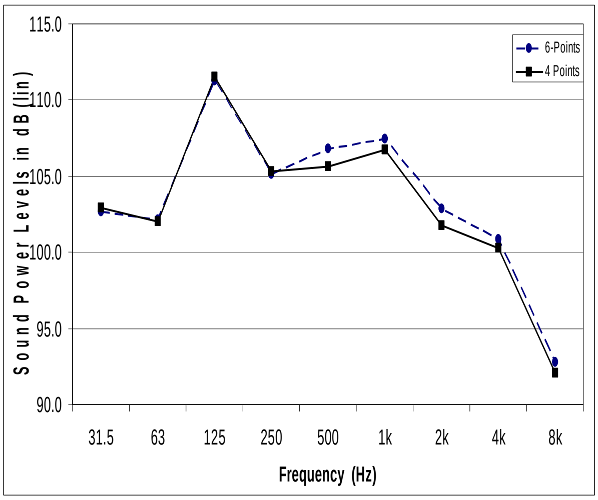

Figure 3. Sound power levels measured under stationary (high-idle) conditions.

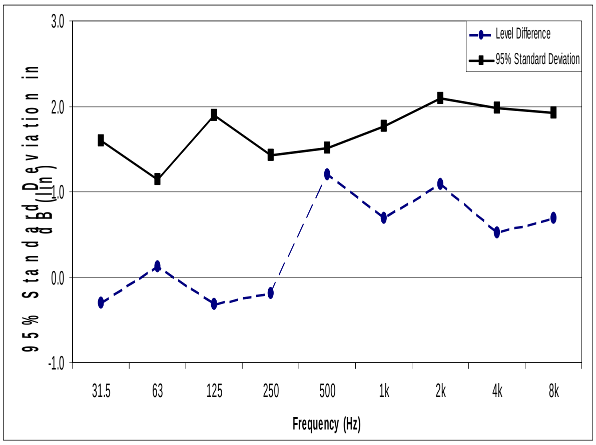

Figure 4. 95% standard deviation for the 4-point method and the level difference.

Measurements on other equipment showed similar results that the 4-point method gave lower values and the overall A-weighted level difference ranged from 0.2 to 2.2 dB(A).

Figure 5 presents the sound power levels measured on the same equipment using different methods. It is shown that the 4-point method gives a similar spectrum shape but (1.3dB) higher estimation than the MDG-15. The noise emission from an equipment under dynamic conditions (drive on a flat compact ground) is much lower than that under stationary (high idle) conditions. Figure 5 presents a typical case from the SVT database, where the overall A-weighted level difference between the results measured using the 4-point method and MDG-15 ranges from 0.5 to 2.8 dB. The A-weighted sound power level of a truck under drive-by conditions is 3.2 to 6.9 dB lower than that under high idle conditions

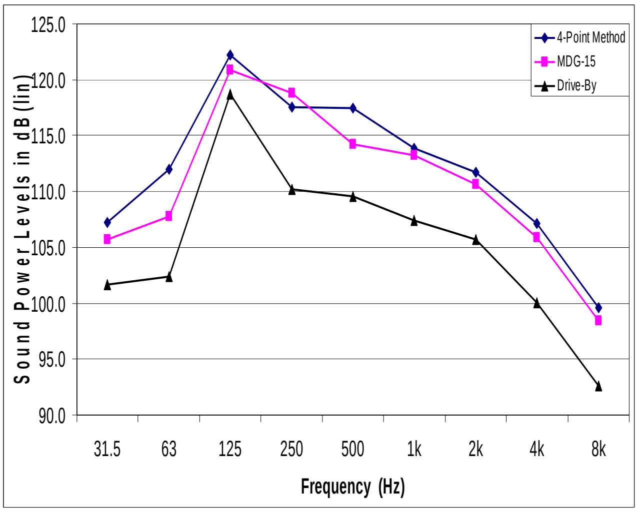

Figure 5. Sound power levels measured on the same earth-moving equipment.

Noise emission from a driving haul-truck also depends on the road and loading conditions. Figure 6 presents the sound power levels measured on a fully loaded haul truck driving on different road conditions, ie flat compact ground, uphill and downhill. It is shown that the truck radiated highest noise when driving uphill, and the lowest noise when driving on flat ground.

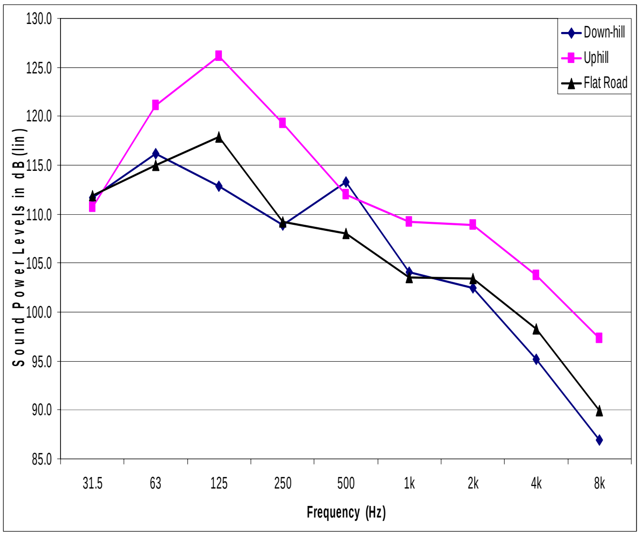

Figure 6. Sound power levels measured on a haul truck driving on different road conditions.

Figures 7 and 8 present the sound power levels measured on a haul truck with and without loads driving downhills and on a flat ground. When driving downhills, the unloaded haul truck radiated higher noise than the fully loaded truck. When a haul truck travels on a flat compact ground, its loading conditions have little impact on its noise emission.

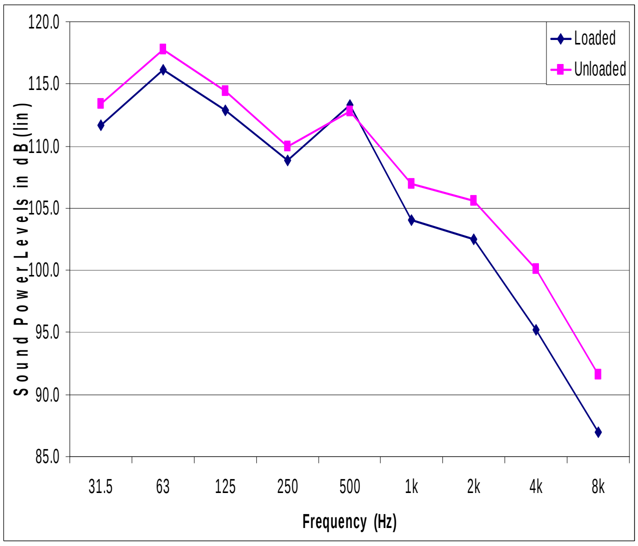

Figure 7. Sound power levels measured on a haul truck driving downhill with and without loaded.

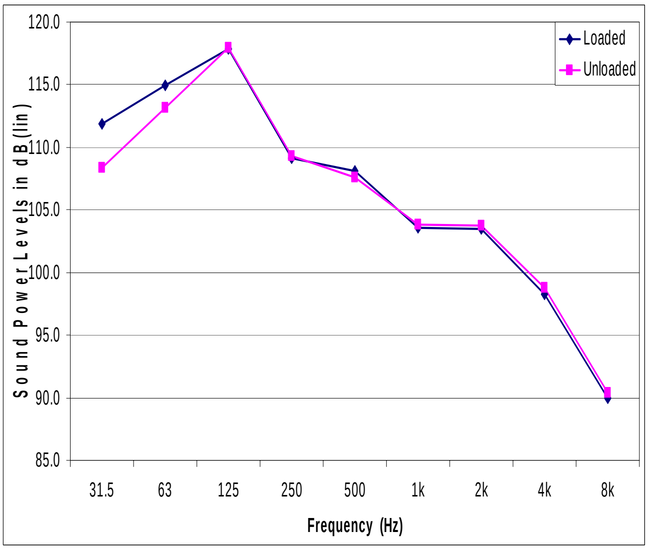

Figure 8. Sound power levels measured on a haul truck driving on a flat ground with and without loaded.

ENVIRONMENTAL MODELLING

Noise models have been created using SoundPlan 6.4 for a mine site. The day-time mining activities involved the operation of 16 mobile equipment, 2 booster pumps and one pit diesel dewatering pump. To calibrate the noise models, spot measurements were undertaken at 9 mine-site boundary locations on a calm sunny day between 1:30pm and 4:00pm. Table 1 presents a comparison between noise levels measured and predicted using the sound power levels estimated from the tests on the mobile equipment under drive-by and high-idle (stationary) conditions. A positive level difference in the table means that the measured noise level is greater than the predicted. This table indicates that a better agreement is achieved between the measurements and predictions if the sound power levels were estimated from the data obtained under the drive-by (dynamic) conditions.

Boundary Locations	Measured	Sound Power Estimated For Mobile Equipment			
		Under Drive-by Conditions		Under High-idle (Stationary) Conditions	
		Predicted	Difference	Predicted	Difference
B1	43.7	44.1	**-0.4**	47.1	**-3.4**
B2	47.6	45.3	**2.3**	48.1	**-0.5**
B3	46.8	47.6	**-0.8**	50.5	**-3.7**
B4	45.3	45.7	**-0.4**	48.3	**-3.0**
B5	43.9	44.6	**-0.7**	47.2	**-3.3**
B6	46.0	45.6	**0.4**	48.0	**-2.0**
B7	43.7	41.3	**2.4**	44.9	**-1.2**
B8	44.6	42.3	**2.3**	46.1	**-1.5**
B9	43.9	42.1	**1.8**	45.2	**-1.3**

Table 1. Measured and predicted noise levels in dB(A)

CONCLUSIONS

This paper presents the measured sound power levels of earth-moving equipment using four methods under field conditions. The results are selected from the SVT database collected for different consulting projects.

Under stationary (high idle) conditions, the ISO (6-point) method and the 4-point method give similar results. The 4-point method has the advantages of time and cost effective, and easy to implement in field conditions. The MDG-15 method gives lower values compared with the ISO method and the 4-point method. The reasons are not discussed here. However, SVT measurements indicated that the agreement became better between the MDG-15 and 4-pintr methods if radius R in the MDG-15 method was the same as the ISO method.

Noise emission for earth-moving equipment under driving conditions is much lower than under high idle conditions. The sound power levels input to noise models should be estimated from the data measured under drive-by conditions. This is because few equipment are operating under high idle (stationary) conditions during mining operations. The sound power measured under stationary conditions may be used to rate (label) the maximum noise emission of equipment, but it does not represent the actual noise emission from its normal operations.

Noise emission from a driving haul truck depends on the road and loading conditions. An uphill driving truck radiates higher noise than a downhill driving truck. An unloaded truck radiates higher noise than a fully loaded truck when driving downhills, but similar noise as a fully loaded truck when driving on flat ground.

DISCUSSIONS AND FURTHER STUDIES

The drive-by method is developed by SVT based on the ISO 6395. The accuracy of this method is not assessed yet. The errors associated with the drive-by method need to be studied under laboratory (controllable) conditions, and if bias errors exist, corrections should be made to field measurement data.

The MDG-15 method was designed for measuring noise emission from earth-moving equipment under field conditions. SVT results indicate that this method produces consistent lower estimation of sound power levels. Study is needed to analysis the errors associated and to assess the accuracy of this method.

REFERENCES

ISO 6393:2008, Earth-moving machinery -- Determination of sound power level -- Stationary test conditions.

ISO 6395:2008, Earth-moving machinery -- Determination of sound power level -- Dynamic test conditions.

Original documents related this measurement method are unable to found. Documents were supplied by BHP Billiton for one of SVT consulting projects.