HAUL TRUCK SOUND POWER ASSESSMENT

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Abstract

Part of the noise impact assessment (NIA) process of current or proposed open cut mines involves predictive noise modelling of mining scenarios to determine an area of affectation. Crucial to predictive noise modelling is accurate sound power level data of the mobile mining equipment to be utilised. ISO [1-3] (International Organisation for Standardisation) and AS [4] (Australian Standard) documents, along with industry developed methodologies, exist for this task and should be utilised when determining equipment sound power levels to be used in NIA modelling, and, determining compliance of equipment eventually used in production with sound power limits extracted from the NIA process. However, these standards and methodologies are often not employed, or are so reduced in scope and detail, that the resultant data is of questionable value and use. Use of questionable methodologies and resultant sound power level data has, in the authors' experience, lead to incorrect model results, sound power specifications not suitable for the intended mine, determination of an incorrect noise affectation area, and, ultimately, significant cost to the mine. Haul trucks are generally the most numerous plant type on a mine site and, as such, accurate determination of haul truck sound power is vital. Two levels of haul truck sound power assessment are presented (compliance and screening) and critical variables for each level of assessment are highlighted and discussed. Results from each level of assessment are compared, showing an agreement between the two methodologies of less than 2 dB/dB(A) (absolute). A theoretical exercise is also undertaken to highlight the effect on results of reducing the number of microphone positions used in determining compliance sound power.

1. Introduction

Accurate sound power level determination of mobile mining equipment is crucial to the mine development/operational process, from the pre-approval planning/modelling process through to equipment compliance monitoring. The most rigorous level of haul truck (and mobile plant in general) sound power assessment can be referred to as a compliance level assessment (compliance in the sense of meeting or not meeting equipment sound power limits), which requires strict control of test parameters and simulation of actual operating scenarios. A reduced scope version of the compliance level test, with a lesser degree of control on test parameters and simulation of operating scenarios, can be used for annual, biennial or triennial 'sound power screening' of mobile equipment to monitor attenuation package (low noise emission muffler/exhausts, absorbent lined engine enclosures, fan noise attenuators) performance; often a regulatory requirement for open cut mines. Sound power screening allows for greater mobility and flexibility of the testing process, while retaining enough methodological rigour to allow for confidence in the results. Haul trucks are generally the most numerous plant type on site. As such, particular attention is given to haul truck sound power determination and monitoring.

2. Comparing assessment methods

Several ISO [1-3] (International Organisation for Standardisation) and AS [4] (Australian Standard) documents exist for sound power assessment of earth moving machinery. Taken separately, each standard falls short of presenting a stand alone document for haul truck sound power assessment, in scope, methodology and real world applicability. AS2012.1-1990 is limited to stationary testing of equipment with no load placed on the engine and no cooling fan speed control. ISO6395-2008 on the other hand, involves dynamic testing of equipment, and incorporates cooling fan speed control, however the specified methods of equipment operation are generally not reflective of actual usage. ISO3744-2010 is more suited to stationary or slow moving noise sources, provides for an overly rigorous test scenario with ten or more microphone positions which would complicate and prolong the time required for testing unnecessarily, however the background noise correction is referenced in ISO6395-20085. When these standards are taken collectively, and with input from industry developed methodologies, a more coherent and rigorous test process emerges.

2.1 Compliance sound power

Compliance sound power assessment involves the most rigorous real-world application of the above mentioned standards and methodologies. Haul truck compliance sound power assessments involve both stationary and dynamic test scenarios. Dynamic testing is performed on a ramp, comprised of stationary, uphill loaded and downhill unloaded (using retard) tests. As the test ramp is generally constrained by a high/low wall and a berm, stationary testing is performed on the ramp and on an open and flat area with no other reflective surfaces nearby (other than the ground) to obtain a ramp correction factor. Table 1 provides a summary of critical test parameters from the above mentioned standards and methodologies.

2.2 Screening sound power

Screening sound power assessment involves a reduced scope version of the full compliance sound power methodology. Haul truck screening sound power assessments generally only involve a dynamic test scenario, being the loudest mode of operation. Dynamic testing is performed on a flat surface removed from any reflective surfaces other than the ground. Trucks (regardless of make or model) approach the test area at low idle and once a signal is given, accelerate at full power through the test area. Table 2 provides a summary of critical sound power screening test parameters, with differences from compliance sound power detailed.

To summarise, the major differences in methodology between compliance and screening sound power are:

- *Microphone positions*; compliance sound power utilises six microphone positions (four ground positions and two elevated positions), whilst screening sound power only utilises four ground positions;
- *Test methodology*; compliance sound power involves stationary testing on a flat surface, and dynamic uphill loaded and dynamic downhill unloaded testing on a ramp, whilst screening sound power generally only involves dynamic testing on the flat; and
- *Engine cooling fan speed*; compliance sound power controls engine fan speed as per ISO 6395-2008, whilst fan speed is not controlled during screening sound power.

Table 1. Compliance sound power critical test parameters

Test Parameter	**Discussion**
Test site requirements	
Background noise	Preferably background is 15 dB < source of interest. If background within 6-15 dB of source, correction made as per ISO3744-2010.
Meteorological conditions	Wind <5m/s No rain Temperature -10°C to 35°C
Environmental correction (reflections)	Trucks are tested 'in situ', as it is important to know the truck sound power in its working environment. Reflections due to high/low walls when testing on a ramp are accounted for by conducting a stationary test on both the ramp and on a flat area free from reflective surfaces (other than the ground), and determining the difference between the two. This difference is then applied to dynamic test results.
Measurement surface	Hemispherical measurement surface as per ISO 6395-2008, of a radius generally twice the major dimension of the machine to be tested.
Microphone positions	Six microphone positions over a hemispherical measurement surface (four ground positions and two elevated positions) as per ISO 6395-2008
Ramp grade	10% ± 1%
Machine requirements	
Engine speed, gear (if applicable) and test condition	Mechanical drive, geared trucks *Stationary – rated engine speed* *Uphill loaded – 1st gear, rated engine speed* *Downhill unloaded – 4th gear 23-25 km/h* Electric drive trucks *Stationary – rated engine speed* *Uphill loaded – high idle engine speed* *Downhill unloaded – 20 km/h*
Cooling fan speed	Engine cooling fan speed is set according to how the fan control system operates, as described in ISO 6395-2008.

Table 2. Screening sound power critical test parameters

Test Parameter	**Discussion**
Test site requirements	
Background noise	As per compliance sound power.
Meteorological conditions	As per compliance sound power.
Environmental correction (reflections)	Test area is a flat open area, removed from reflective surfaces other than the ground.
Measurement surface	As per compliance sound power.
Microphone positions	**Four** microphone positions over a hemispherical measurement surface as per ISO 6395-2008. Elevated microphone positions are omitted to allow for test team mobility and efficiency gains.
Ramp grade	Not applicable
Machine requirements	
Engine speed, gear (if applicable) and test condition	Mechanical drive, geared trucks *Dynamic forward – 1st gear high idle* Electric drive trucks *Dynamic forward – high idle*
Cooling fan speed	Engine cooling fan speed is not controlled.

3. Compliance and Screening Sound Power Results Comparison

Table 3 compares results of compliance (uphill loaded test) and screening (dynamic forward test) sound power assessments on 29 trucks at a variety of mine sites. A mixture of mechanical and electric drive trucks were tested, with a variety of engine cooling fan types. A filter was applied to remove compliance and screening results with a greater than three year gap between test dates, in an attempt to remove the possibility of engine re-powering between tests. Table 3 shows that while results can vary by as much as 4 dB, on average an agreement between haul truck compliance (uphill loaded) and screening (dynamic forward) sound power methodologies of less than 2 dB (absolute) for linear (1.6 dB) and A-weighted (1.3 dB) is observed. Compliance sound power results were higher than screening sound power results 69 percent of the time for linear sound power, and 76 percent of the time for A-weighted results.

Tables 1 and 2 detail the differences between haul truck compliance and sound power screening procedures, including changes in test methodology, cooling fan speed control and number of microphone positions. While the influence of test methodology and cooling fan speed control variables cannot be individually quantified from Table 3 data, a theoretical exercise can be undertaken using compliance sound power results to provide some indication of the effect of the number of microphone positions variable (six for compliance v four for screening) in determining overall sound power. Results are presented in Section 4.

Additional variables which may have impacted on Table 3 results include degradation, or removal of, any attenuation package (such as low noise emission muffler/exhausts, absorbent lined engine enclosures, fan noise attenuators) fitted to the haul truck between the two test dates. While removal of truck attenuation components cannot be ruled out entirely, it is noted that an audit of attenuation components was carried out on over 75% of the haul trucks presented in Table 3 as part of the screening process, to ensure all components were present. This leaves degradation of attenuation component performance as a relatively unknown quantity. In an ideal world, removal of the attenuation component degradation variable would be achieved through performing both the compliance and screening sound power tests on the same day.

4. Effect of microphone positions included in calculation of overall sound power levels

A theoretical exercise was undertaken to provide insight into the effect of the number of microphone positions variable (six for compliance v four for screening) on sound power results. The exercise also served to highlight the danger in reducing the number of microphone positions utilised in the compliance sound test procedure. Tables 4 to 7 present compliance sound power results for theoretical trucks A and B. The two left hand columns provide sound power results for each individual ground microphone position. The two right hand columns show overall sound power levels as calculated from combinations all six positions, the four ground positions only, and the two LHS and RHS ground positions only. Tables 4 to 7 show that while A-weighted results displayed no change, linear results showed a small increase (up to 1 dB), when elevated microphone positions five and six were removed from the calculation, indicating that the number of microphone positions variable (compliance v screening sound power) is potentially only significant for linear sound power results.

As shown in Tables 4 to 7, the sound power level of haul trucks (A) and (B) varies only slightly from the six position compliance result when the overall sound power is calculated using the four ground positions only. When overall sound powers were calculated using only the two LHS microphone results, a decrease of up to 5 dB and 3 dB(A) from the six position compliance result was observed. When overall sound powers were calculated using only the two RHS microphone results an increase of up to 4 dB and 3 dB(A) from the six position compliance result was observed.

Table 3. Compliance and screening sound power results comparison

	Dynamic uphill loaded Compliance L_W[1]		Dynamic forward Screening L_W		L_W difference Compliance minus Screening	
Truck ID	dB	dB(A)	dB	dB(A)	dB	dB(A)
1	122	115	121	114	-1	-1
2	123	115	122	116	-1	1
3	122	115	121	114	-1	-1
4	123	116	122	117	-1	1
5	122	115	121	114	-1	-1
6	123	115	124	118	1	3
7	122	115	121	114	-1	-1
8	123	117	123	115	0	-2
9	123	116	123	116	0	0
10	122	115	123	114	1	-1
11	122	116	125	117	3	1
12	122	116	122	115	0	-1
13	122	115	120	115	-2	0
14	121	116	123	116	2	0
15	121	115	123	116	2	1
16	123	115	122	115	-1	0
17	119	113	121	114	2	1
18	119	113	122	115	3	2
19	119	112	122	115	3	3
20	120	114	121	115	1	1
21	124	115	125	118	1	3
22	127	119	129	122	2	3
23	127	119	129	120	2	1
24	127	119	129	120	2	1
25	126	119	129	121	3	2
26	135	124	135	125	0	1
27	122	113	121	113	-1	0
28	118	112	122	115	4	3
29	117	112	121	115	4	3
Average L_W difference (absolute)					2	1

Note

1. *Sound power level, expressed in decibels, is the logarithmic ratio of the sound power of a source in watts (W) relative to the sound power reference base of 10^{-12} W*

Table 4. Haul Truck (A) Linear sound power

Microphone position	**L_W**	**Combined position result**	**L_W**
Ground 1 Front LHS	128	1 – 6 (compliance result)	133
Ground 2 Rear LHS	128	Ground 1 – 4	134
Ground 3 Rear RHS	137	LHS Ground 1 and 2	128
Ground 4 Front RHS	136	RHS Ground 3 and 4	137
Elevated 5 LHS	125		
Elevated 6 RHS	134		

Table 5. Haul Truck (A) A-weighted sound power

Microphone position	**L_W**	**Combined position result**	**L_W**
Ground 1 Front LHS	117	1 – 6 (compliance result)	117
Ground 2 Rear LHS	113	Ground 1 – 4	117
Ground 3 Rear RHS	119	LHS Ground 1 and 2	114
Ground 4 Front RHS	120	RHS Ground 3 and 4	120
Elevated 5 LHS	112		
Elevated 6 RHS	119		

Table 6. Haul Truck (B) Linear sound power

Microphone position	**L_W**	**Combined position result**	**L_W**
Ground 1 Front LHS	129	1 – 6 (compliance result)	131
Ground 2 Rear LHS	127	Ground 1 – 4	132
Ground 3 Rear RHS	131	LHS Ground 1 and 2	128
Ground 4 Front RHS	135	RHS Ground 3 and 4	133
Elevated 5 LHS	124		
Elevated 6 RHS	132		

Table 7. Haul Truck (B) A-weighted sound power

Microphone position	**L_W**	**Combined position result**	**L_W**
Ground 1 Front LHS	118	1 – 6 (compliance result)	119
Ground 2 Rear LHS	116	Ground 1 – 4	119
Ground 3 Rear RHS	116	LHS Ground 1 and 2	117
Ground 4 Front RHS	122	RHS Ground 3 and 4	120
Elevated 5 LHS	114		
Elevated 6 RHS	121		

5. Summary

Compliance sound power represents a comprehensive approach to haul truck sound power testing. Screening sound power utilises a reduced scope version of the compliance test procedure, enhancing test team flexibility, mobility and efficiency, and is often used for annual, biennial or triennial sound power testing of mining plant. A comparison of results obtained from both methodologies has shown a good agreement, less than 2 dB/dB(A) (absolute), even with a reduction in microphone positions and significant change in test procedure. In general, compliance sound power levels were found to be higher than screening sound power levels for the same truck. A theoretical exercise was carried out to provide insight into the effect of the number of microphone positions variable (six for compliance v four for screening) on sound power results. The exercise also served to highlight the danger in reducing the number of microphone positions utilised in the compliance sound power test procedure, with sound powers determined using only two microphone position (LHS or RHS) results varying by as much as 5 dB and 3 dB(A) (absolute) from the six position compliance result.

Haul trucks are generally the most numerous plant item on a mine site, as such their contribution to overall site noise levels is significant. Sound power assessment of haul trucks for use in NIA modelling or for determining if a haul truck is under a specified sound power limit (a limit generally derived from the NIA process), should preferentially make use of the compliance level sound power assessment, with any use of the screening level assessment process or results, being done so with caution, and on a case by case basis. Care should also be taken, when considering a reduction in the number of microphone positions utilised in the compliance level assessment.

References

[1] ISO 3744:2010 Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Engineering methods for an essentially free field over a reflecting plane, *International Organisation for Standardisation*, Geneva, Switzerland, 2010.

[2] ISO 6393:2008 Earth-moving machinery – Determination of sound power level – Stationary test conditions, *International Organisation for Standardisation*, Geneva, Switzerland, 2008.

[3] ISO 6395:2008 Earth-moving machinery – Determination of sound power level – Dynamic test conditions, *International Organisation for Standardisation*, Geneva, Switzerland, 2008.

[4] AS 2012-1:1990 Acoustics – Measurement of airborne noise emitted by earth-moving machinery and agricultural tractors – Stationary test condition - Part 1: Determination of compliance with limits for exterior noise, *Standards Association of Australia*, Homebush, Australia, 1990.