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Motor Racing Vehicles - Measurement Methods

Development of Noise Emission Measurement Methods for Motor Racing Vehicles

Ingemansson Technology AB

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Contents

Summary and conclusions

Based on the existing pool of noise data, two simple methods for measuring noise emission from motor racing vehicles have been formulated.

The declaration method is intended for provision of noise emissions values for a type or class of motor sports vehicles to be used as input to noise predictions around racetracks. The method is based on measurement of L_{eq} during passby of a number of vehicles at full load of the engine. The uncertainty is estimated to be 3 dB.

The monitoring method is intended for surveying the noise emission of individual vehicles during racing events. The method is based on measurement of L_{pAmaxF} during passby at full load of the engine. The uncertainty is estimated at 4 dB.

Resume

Motorsportens organisationer har ønsket, at der blev udviklet en mere enkel metode til måling af støjemissionen (kildestyrken) fra motorsportskøretøjer end den metode, som er brugt til de målinger, der indgår som bilag i Miljøstyrelsens vejledning 3/1997 "Støj fra motorsportskøretøjer". Herved ville det blive enklere at ajourføre vejledningens bilag både med nye typer af køretøjer og med opdaterede data for de bestående typer og klasser. Desuden var der et ønske om at udvikle en meget enkel kontrolmetode, som de enkelte klubber selv kan benytte, fx i forbindelse med løb, til at sikre at alle køretøjerne overholdt organisationernes støjkrav. Miljøstyrelsen kunne tilslutte sig ønsket om enklere målemetoder, og støttede udviklingen af målemetoderne indenfor rammerne af "Renere Produkter" tilskudsordningen. Arbejdet er udført af Ingemansson Technology i perioden 1997 – 99.

Rapporten her beskriver udviklingen af de to enkle metoder til måling af støjemission fra motorsportskøretøjer. Arbejdet er baseret på analyse og behandling af foreliggende data.

Deklarationsmetoden er beregnet på måling af generelle data for støjemissionen for en type eller klasse af køretøjer, som benyttes som indgangsdata ved beregning af støjniveauet i en motorsportsbanes omgivelser. Målemetoden er baseret på måling i oktavbånd af ækvivalentniveauet L_{eq} under forbikørsel af et antal køretøjer under maksimal belastning. Ubestemtheden anslås til 3 dB.

Kontrolmetoden er beregnet på at undersøge støjemissionen fra de enkelte køretøjer under løb. Ved metoden måles L_{pAmaxF} ved passage af køretøjet under maksimal belastning. Ubestemtheden anslås til 4 dB.

1 Introduction

In order to regulate the noise impact of motor racetracks in the surrounding environment, the authorities have set limits for noise immission from racetracks. Due to the inherent difficulties concerning performance of reliable noise immission measurements at larger distances from the racetrack, prediction of the noise immission is a widely accepted method.

As input to the prediction models, a declaration of the noise emission of the racing vehicles is necessary. In order to predict a realistic noise immission, the noise emission must reflect the noise produced by the vehicles during normal racing conditions, i.e. it shall be immission relevant.

Further, periodical monitoring of the immission relevant noise emission for individual vehicles is necessary. This is done by the motor sport organisations at regular intervals during the season.

The purpose of this project is to develop simple and reliable methods for measurement of these noise emissions, i.e. a noise declaration and a monitoring method.

2 Basic principles

The following terminology is used in this report:

- **Noise**. General term characterising sound from racing vehicles.
- **Noise level**. A-weighted sound pressure level in dB re. 20µPa. (LpA). The instantaneous noise level can be determined with integration time corresponding to FAST (L_{pAF}) or SLOW (L_{pAS}).
- **Maximum noise level**. The maximum value of L_{pAF} measured during passby of a single racing vehicle (L_{pAmaxF}).
- **Energy equivalent sound pressure level**, $L_{Aeq,T}$ is the A-weighted energy mean of the noise level averaged over the measurement period.

$$L_{Aeq,T} = 10 \cdot \log \frac{1}{T} \int_0^T \frac{p_A^2(t)}{p_0^2} dt$$

- **Noise immission**. Energy equivalent A-weighted sound pressure level in dB re. 20µPa, (L_{AeqT}), measured or predicted over the time interval T (normally 1 hr.), at some distance from a racetrack, typically at dwellings.
- **Noise emission**. Sound power level (L_W) in dB re. 1pW characterising the noise radiation from a vehicle. The noise emission can be A-weighted (L_{WA}), or expressed in frequency bands, usually 1/3 or 1/1-octave bands. For declaration purposes, the noise emission can be an average level for a group of vehicles. For monitoring purposes, the noise emission is determined for a single vehicle.
- **Ground correction**. A correction term characterising the influence upon the sound propagation due to the acoustic properties of the ground between a noise source and a microphone. The ground correction is an important part of the noise emission determination as well as of the prediction of the noise immission.

3 Existing measurement methods

For the last two decades the following noise measurement methods have been widely used in Denmark.

1. L_{pA} monitoring method used by the motor sport organisations. The steady noise is measured close to a stationary vehicle at a specified engine revolution. As the engine is unloaded, and not necessarily running at realistic maximum racing speed, this method correlates poorly with the immission relevant noise emission.
2. L_{pAmaxF} monitoring method used by the motor sport organisations for karting. The noise is measured close above a passing vehicle during normal racing. This method correlates relatively well with the immission relevant noise emission, but is only implemented for karting vehicles and not for general use
3. 1/3-octave declaration method used by acoustic laboratories for measurement of the noise emission relevant for noise immission. This is a passby method where the sound power level is determined at realistic racing conditions. The noise level is integrated during the passby, and a relative complicated integrated ground correction term is applied in order to determine the noise emission. Therefore, a new declaration method using a less elaborate ground correction term, will facilitate more frequent declaration measurements, and thus a more updated database of noise emission values for racing vehicles. This method is further described in ref. 1.

4 Functional requirements

The new methods shall be simple and easy to use, and have an acceptable low measurement uncertainty. Specifically the following requirements shall be aimed at:

4.1 Declaration method:

- Immission relevant sound power level per 1/1-octave frequency bands.
- Best possible agreement with results obtained with the existing method No. 3, which a priori is defined as giving a correct immission relevant noise emission.
- Applicable for all relevant vehicles.
- Relatively simple ground correction.
- Ability to use for non-high level experts.

4.2 Monitoring method

- Immission relevant A-weighted sound power level.
- Agreement with results from the declaration method.
- Applicable for all relevant vehicles.
- Simple ground correction.
- Ability to use for non-experts during training and race events.

5 Development methodology

5.1 General

Based on the functional requirements, the following basic features were initially evaluated and determined.

- The declaration method shall be based on L_{eq} measurements of passing vehicles. This method is particularly suitable when determining an average noise emission for a class of similar vehicles.
- The monitoring method shall be based on measurement of L_{pAmaxF} or L_{pAmaxS}. This procedure is particularly suitable when determining noise emission from individual passing vehicles.

In order to minimise the amount of new measurements in the project, the existing pool of noise emission data was utilised. Ref. 1-3 contain a comprehensive amount of data, and these data were used as a basis for the development of the new methods.

As described in ref. 1, the existing declaration method is based on L_{eq} measurements, and gives the immission relevant sound power level per 1/3-octave bands. It was therefore found that this method would be the best basis for the new declaration method.

However, determination of 1/3-octave noise emission is found to be an unnecessary complication, as the present relevant prediction models only utilise 1/1-octave bands anyway.

The crucial point in the existing method is the ground correction, which is a computed value integrated over the segment of the track where the noise is measured. Further, the ground correction is based on specific knowledge of the acoustic flow resistance of the ground in question. This is considered to be a too complicated procedure for more widespread use of this method.

The main point of the development methodology has therefore been development of a less complicated ground correction term, while reasonably maintaining the accuracy of the existing method.

5.2 Analysis of existing data

Basically, the existing declaration method can be expressed as:

$$L_W = L_{eq} + K - \Delta L_g, \text{ where}$$

ΔL_g is the ground correction term and K represents a combination of other parameters such as distance, driving speed, etc.

In order to investigate the impact of a new less complicated ground correction term, the following analysis was performed for the noise emission data from ref. 1-3:

- The original ground correction ΔL_g was added to the 1/3-octave L_w-values.
- The corrected L_w-values were converted to 1/1-octave levels.
- Alternative ground correction terms were subtracted from the corrected L_w levels, thus giving new sound power levels per 1/1-octave. These new levels simulate the situation where the original measurements had been performed in 1/1-octave bands with a relatively simple ground correction term.

To evaluate the quality of the alternative ground correction terms, the new sound power levels were compared with the original levels.

The initial approach was to calculate new ground corrections according to the analytical method given in ref. 4 for three types of racetracks. This method gives the point-point ground correction, whereas the original ground correction integrates the acoustic properties of the surface between the complete driving path and the microphone position. As a basis for the alternative ground correction terms, the following three acoustic ground properties were assumed in the investigation.

1. Soft (acoustic absorbing) surface for the complete propagation path.
2. Hard (acoustic reflecting) surface for the complete propagation path.
3. Hard surface under the source, and soft surface under the microphone.

The point to point ground corrections were determined in 1/1-octave bands according to ref. 4 for the transmission path corresponding to the shortest distance between source and microphone.

The result of the initial noise emission analyses show, however, that no acceptable agreement with the original noise emission could be achieved using the analytical point-point ground correction from ref. 4. There was a general trend towards underestimating the noise emission (total L_{wA}) with up to 4 dB. It is our evaluation that this disagreement is caused by the different approaches between the two ground corrections. The original correction is determined as an integrated value over the same integration path as the noise (L_{eq}) is measured and integrated. The point-point ground correction from ref. 4 is based on a restricted part of the noise transmission path only, and may therefore differ from a ground correction based on the complete transmission path.

Therefore an alternative approach was used. The ground correction was defined for three racetrack types, as those ground correction values that empirically gave the best agreement with the original measurements. Those ground corrections are fixed values that depend only upon the type of racetrack and not on the actual geometry of the measurements. This approach has the following advantages and disadvantages:

- The agreement with the original measurements will be the best possible.
- The procedure differs from the normal procedure for determination of ground corrections

- Certain restrictions concerning measurement distance and microphone height will have to be accepted.

As agreement with the original measurements had the highest priority, the steering committee of the project determined to support the definition approach, even if this means that the normal analytical procedure for determining the ground correction cannot be used in connection with motor racing vehicles. It was, however, not considered acceptable to support a procedure that in general underestimates the noise emission. The definition approach resulted in the ground corrections shown in Table 1.

5.3 Evaluation of new declaration ground correction

Figure 1 to 3 shows a summary of the difference between the original sound power levels and the levels determined with the alternative ground corrections. This analysis is based on ref. 1-3, which comprises a number of motocross- speedway- and karting racetracks.

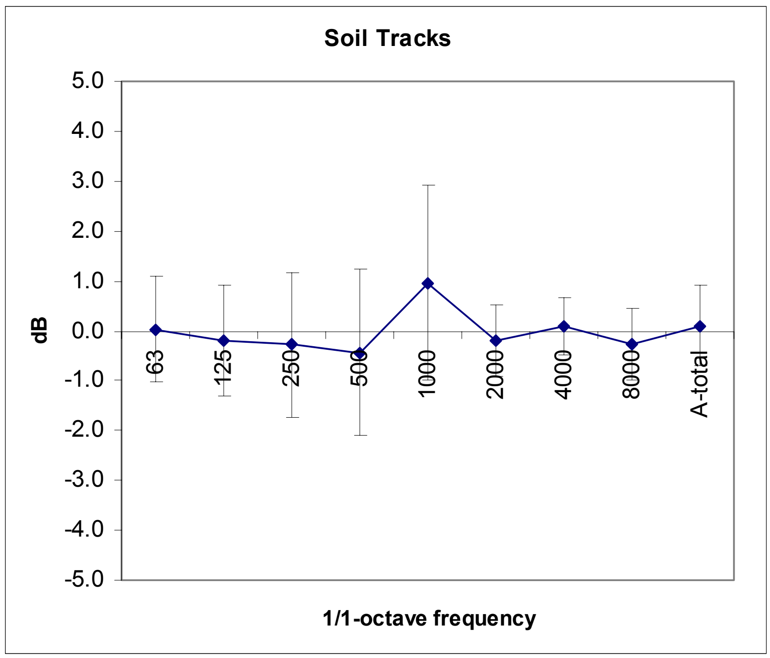

Figure 1. New Lw - original Lw. Average values and standard deviations for Moto Cross (Soil tracks)

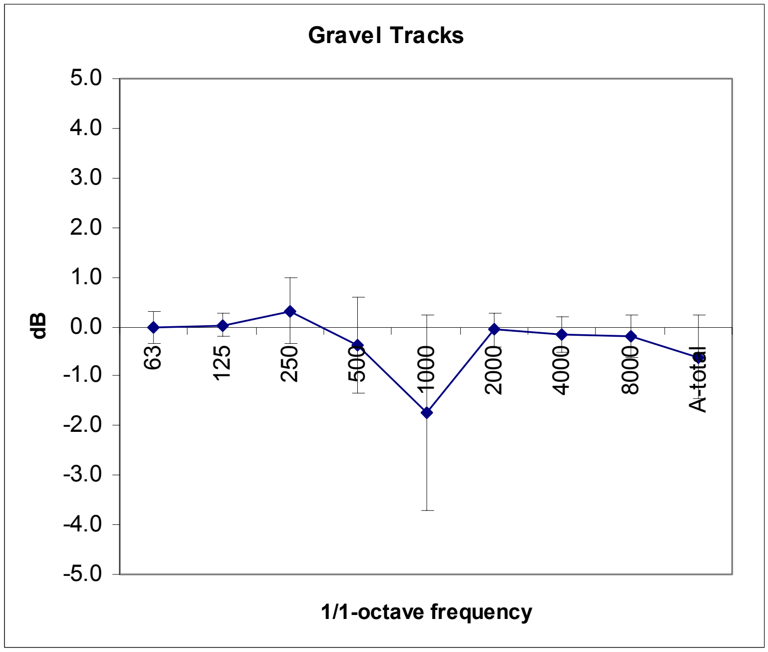

Figure 2. New Lw - original Lw. Average values and standard deviations for speedway (Gravel tracks)

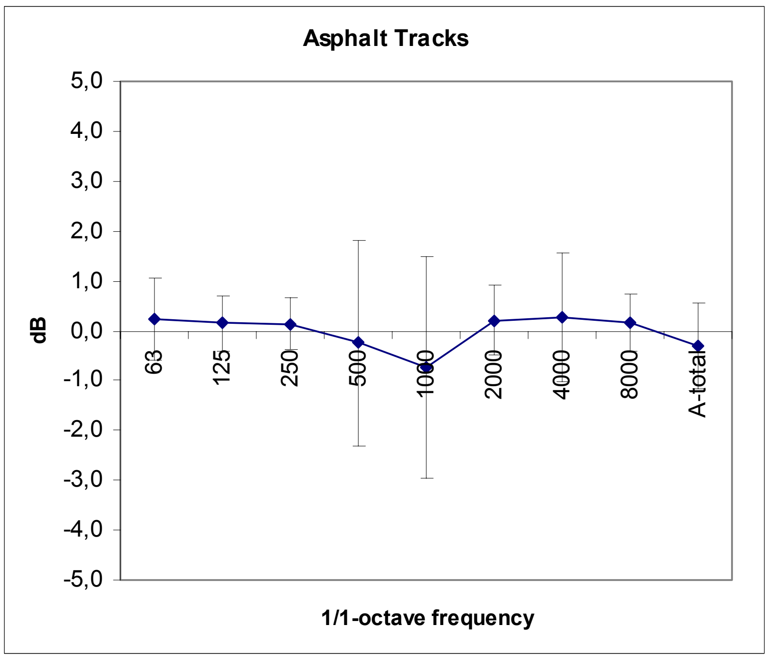

Figure 3. New Lw - original Lw. Average values and standard deviations for Karting (Asphalt tracks)

As expected, the average deviation between the original noise emission and the noise emission obtained with the new ground corrections is small. This is a consequence of the definition approaches. Thus, the uncertainty contribution from the ground correction is estimated at 1-2 dB.

5.4 Evaluation of new monitoring ground correction

It was initially decided that L_{eq} is the best available descriptor for declaration purposes, as L_{eq} implicitly averages the noise emission from the individual vehicles on an energy basis, thus creating the noise emission for an average vehicle. For the monitoring method, however, a descriptor characterising the noise emission of each individual vehicle is necessary. Therefore L_{pAmaxF} was selected for this purpose.

In order to formulate the ground correction for the monitoring method, supplementary measurements were performed for Speedway, Cross and Karting. The purpose of the measurements was to establish the relationship between sound power levels and maximum sound pressure levels for typical racing vehicles under realistic racing conditions, as these values were not included in the existing pool of data.

Due to budget and time constraints only a limited number of measurements were possible. The number of measurements and the representativity of the tested vehicles do not fulfil the recommendations for normal declaration measurements. The measurement conditions and results are described in Appendix.

For each type of vehicle, the following analyses were performed: First the sound power level was determined using the declaration method (L_{eq}) and the ground corrections determined by the definition approach. Then this sound power level was combined with the simultaneously measured $L_{pAmax\ F}$ – values in order to determine the ground corrections for the monitoring method:

1) Declaration: $L_W = L_{q,t} + 10 \log(4vat) - \Delta L_{gd} - 10 \log N$

where v is the driving speed, t is the integration time, a is the average minimum distance between vehicle and microphone, N is the number of passing vehicles in the integration time, and ΔL_{gd} is the ground correction given in table 1.

2) Monitoring: $L_{WA} = L_{pAmax\ F} + 10 \log (4 \pi a^2) - \Delta Lg$

The A-weighted declaration values were determined using expression 1. These values were then inserted in expression 2 together with the measured $L_{pAmax\ F}$ levels. Then the monitoring method ground corrections ΔL_g were determined from expression 2 (the monitoring method is restricted to total A-weighted levels). These values are shown in Figure 2. One may argue that the values in Table 2 theoretically are expected to be in the interval 8 – 11 dB instead of the actual interval 6.7 – 12.8 dB. It shall, however, be borne in mind, that the theoretical 8 –11 dB correction refers to a point to point sound propagation situation for omnidirectional point sources, while the values in Table 2 implicitly refers to an integrated sound transmission path for sound sources that are not necessarily omnidirectional. Thus, there is no direct link between the two procedures and corrections.

6 Proposal for new methods

6.1 Declaration method

Based on the above analyses, the following noise declaration method is proposed based on 1/1-octave band levels:

$$L_W = L_{eq,t} + 10 \log 4vat - \Delta L_{gd} - 10 \log N, \text{ where}$$

- L_W is the energy equivalent immission relevant sound power level per 1/1-octave frequency band in dB re. 1pW.
- $L_{eq,t}$ is the energy equivalent sound pressure level per 1/1-octave frequency band in dB re. 20µPa measured over an integration time interval t.
- v is the average passby driving speed in m/s.
- a is the shortest distance from the microphone to the centre line of the track. The distance from the microphone to the individual vehicle may vary within ± 10%.
- t is the integration time in seconds.
- N is the number of passbys.
- ΔL_{gd} is the ground correction for declaration purposes, defined in Table 1.

This method gives the average immission relevant noise emission for one vehicle. The microphone position shall be chosen at a straight section of the track, where the vehicles yield maximum engine power, e.g. after a curve. The measurement section shall be as long as possible, preferably 10 times the measurement distance a, which shall be in the range 4-10 m. There shall be no significant sound reflecting or screening obstacles close to the measurement area. The microphone shall be 1.5-1.8 meters above the ground. In case of measurement of noise from speedway motorcycles, the microphone shall be placed above the security fence around the track, and likewise 1.5 m to 1.8 m above the track surface.

1/1-Octave frequency [Hz]	Soil tracks		Gravel tracks		Asphalt tracks		
Microphone pos:	soft surface		soft surface		soft surface		hard surface
	average	st.dev.	average	st.dev.	average	st.dev.	average
63	4.1	0.9	5.2	0.2	5.0	0.7	4.3
125	3.7	0.8	4.7	0.2	5.1	0.3	9.6
250	1.2	1.5	2.3	0.7	4.3	0.8	4.1
500	-4.2	2.0	-1.1	0.3	1.3	2.1	1.1
1000	-0.9	3.1	1.4	0.3	-0.7	3.4	0.5
2000	0.1	0.6	1.2	0.4	1.0	0.8	3.7
4000	-0.2	0.7	1.1	0.4	0.5	1.4	1.5
8000	-0.1	0.7	0.4	0.5	1.3	0.7	1.2

Table 1. Ground corrections for declaration purposes ΔL_{gd} in dB

Table 1 shows the ground corrections as defined for 3 typical racetracks. Measurements performed on soil tracks and gravel tracks shall be done over an acoustically soft surface, e.g. grass or soil.

Measurements on asphalt tracks can be made with the microphone positioned above either an acoustically soft surface or a hard surface. The values for ***Asphalt tracks/hard surface*** are however based on noise measurements from only one vehicle.

As shown in ref. 2, the primary variable regarding measurement uncertainty is the number of passbys. With N = 30, the uncertainty may be estimated at 3 dB, given as a 90% confidence level.

For measurements of new declaration values at least 30 passbys from at least three different vehicles shall be measured and averaged on an energy basis. The passbys shall be evenly distributed between the vehicles and representative vehicles shall be used.

6.2 Monitoring method

Based on the above analyses, the following noise monitoring method is proposed, based on measurement of A-weighted maximum levels:

$$L_{WA} = L_{pAmaxF} + 10 \log(4 \pi a^2) - \Delta L_g$$
$$\Downarrow$$
$$L_{WA} = L_{pAmaxF} + 20 \log a + 10 \log(4 \pi) - \Delta L_g$$
$$\Downarrow$$
$$L_{WA} = L_{pAmaxF} + 20 \log a + \Delta L_{gm}, \text{ where}$$

- L_{WA} is the energy equivalent immission relevant A-weighted sound power level in dB re. 1pW.
- L_{pAmaxF} is the maximum A-weighted sound pressure level dB re. 20µPa, measured with integration time FAST.
- a is the minimum distance between the individual vehicle and the microphone in m.
- ΔL_{gm} is the ground correction for monitoring purposes, defined in Table 2. For simplicity reasons $\Delta L_{gm} = 10 \log(4 \pi) - \Delta L_g$.

This method gives the A-weighted immission relevant noise emission for one specific vehicle. The microphone position shall be chosen at a straight section of the track, where the vehicles yield maximum engine power, e.g. after a curve. The measurement distance a shall be in the range 4-10 m. There shall be no significant sound reflecting or screening obstacles close to the measurement location. The microphone shall be 1.5-1.8 meters above the ground. In case of measurement of noise from speedway motorcycles, the microphone shall be placed above the security fence around the track, and likewise 1.5 m to 1.8 m above the track surface.

Ground correction (dB)	Soil tracks	Gravel tracks	Asphalt tracks	
Microphone ground	Soft	Soft	Soft	Hard
ΔL_{gm}	10.7	12.8	9.4	6.7

Table 2. Ground corrections for monitoring purposes ΔL_{gm} in dB

Table 2 shows the ground corrections as defined for three typical racetracks. However, in order to facilitate monitoring measurements at asphalt tracks, a correction for microphone positions above a hard surface has been included.

As shown in ref. 2, the primary variable regarding measurement uncertainty is the number of passbys. With N = 4, the uncertainty associated with the average value of L_{pAmaxF}, and thereby L_{WA}, may be estimated to 4 dB, given as a 90% confidence level. It is therefore recommended that monitoring shall be based on the average value of 4 passbys, as the result based on e.g. a single passby may be too uncertain.

7 Concluding remarks

Based on the existing pool of noise data, two simple methods for measuring immission relevant noise emission from motor racing vehicles have been formulated.

The declaration method is intended for provision of noise emissions to be used as input to noise predictions around racetracks. The method is based on measurement of L_{eq} per 1/1-octave during passby at full load of the engine. The 1/1-octave uncertainty is estimated to 3 dB provided at least 30 passbys of at least three vehicles is used

The monitoring method is intended for surveying the noise emission of individual vehicles during racing events. The method is based on measurement of L_{pAmaxF} during passby at full load of the engine. The uncertainty is estimated at 4 dB for an average value of four measurements.

8 References

1) Støj fra motorsportskøretøjer. Emissionskatalog 1982. Motocross, Speedway, Karting. Ødegaard & Danneskiold Samsøe.
2) Støj fra motorsportskøretøjer. Emissionskatalog 1991. Motocross, Speedway, Karting. Ødegaard & Danneskiold Samsøe.
3) Buller från motorsportsfordon. Emissionskatalog 1991. KM Akustikbyrån.
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Appendix

Measurement Results

This Appendix documents measurements where the proposed measurement methods for declaration as well as for monitoring purposes were used in practise. The measurement results form the background for the proposed ground corrections for monitoring purposes.

The measurements were made at three different racing tracks:

1. A karting track (Copenhagen Karting)
2. A cross track (Hedeland Cross)
3. A speedway track (Slangerup Speedway)

1 Karting – Asphalt Track

Location	Copenhagen Karting								
Date	99.07.01								
Vehicle	One POP 1-class kart, 10 passbys								
Microphone 1	1.5 m above soft ground (grass), 7.5 m from actual racing line								
Microphone 2	1.5 m above hard ground (concrete), 7.5 m from actual racing line								
Speed	Average driving speed on measurement section of track: 30 m/s								
Frequency (Hz)	63	125	250	500	1k	2k	4k	8k	Total
L_{WA} (dB re. 1pW)	67.9	78.1	105.2	112.7	118.7	124.4	120.7	114.5	127.1
L_{pAmaxF} (soft) (dB re. 20µPa)	-	-	-	-	-	-	-	-	100.2
L_{pAmaxF} (hard) (dB re. 20µPa)	-	-	-	-	-	-	-	-	103.0

2 Cross – Soil Track

Location	Hedeland Cross								
Date	99.07.13								
Vehicle	One 250cc-class solo mc, 10 passbys								
Microphone	1.5 m above ground (soil), 7.5 m from actual racing line								
Speed	Average driving speed on measurement section of track: 21 m/s								
Frequency (Hz)	63	125	250	500	1k	2k	4k	8k	Total
L_{WA} (dB re. 1pW)	73.6	102.9	110.1	120.1	118.7	118.7	118.4	112.8	125.5
L_{pAmaxF} (dB re. 20µPa)	-	-	-	-	-	-	-	-	97.3

3 Speedway – Gravel Track

Location	Slangerup Speedway								
Date	99.05.22								
Vehicle	One 500 cc-class, 3 different exhaust silencers, 4 passbys each								
Microphone	1.5 m above ground (at security fence), 8.5 m from actual racing line								
Speed	Average driving speed on measurement section of track: 24 m/s								
Frequency (Hz)	63	125	250	500	1k	2k	4k	8k	Total
L_{WA1} (dB re. 1pW)	99.7	112.5	124.2	130.9	123.1	122.4	119.8	118.0	133.1
$L_{pAmaxF1}$ (dB re. 20µPa)	-	-	-	-	-	-	-	-	102.3
L_{WA2} (dB re. 1pW)	99.7	112.3	124.0	131.5	123.6	121.9	119.6	118.0	133.5
$L_{pAmaxF2}$ (dB re. 20µPa)	-	-	-	-	-	-	-	-	102.5
L_{WA3} (dB re. 1pW)	102.3	114.1	126.1	135.9	127.3	126.8	125.3	120.2	137.6
$L_{pAmaxF3}$ (dB re. 20µPa)	-	-	-	-	-	-	-	-	105.9