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NOISE CONTROL FOR A BETTER ENVIRONMENT

Measurement of Sound Power Level of Electric Vehicles in Steady Low Speed Travelling

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ABSTRACT

The vehicles that are propelled by electric motors are becoming popular, and the number of production is rapidly increasing recently. While the electric and hybrid electric vehicles (EV, HEV) has major population in such vehicle, fuel cell vehicles (FCV) are also introduced in the family. The propulsion noise of such vehicles are lower than conventional internal combustion engine vehicles (ICEV), particularly at low speeds. It is a keen interest to examine the noise reduction effect of such vehicles. In order to introduce EVs into the noise prediction models, such as ASJ RTN-Model or CNOSSOS-EU, it is necessary to know the sound power level emitted by an electric vehicle and to develop a model of sound power level depending on the vehicle speed. In this research, several measurements on sound power level were carried out on a dense asphalt pavement. The result showed that the sound power level of test EVs in 20 to 30 km/h speed range were 2 to 4 dB lower than the ICEV. Additionally, the comparison of the frequency analysis was conducted to evaluate the effect of Acoustic Vehicle Alerting System (AVAS) to improve the auditory detectability by pedestrians.

Keywords: Electric Vehicle, Sound Power Level, Traffic Noise
I-INCE Classification of Subject Number: 13, 76

1. INTRODUCTION

Electric vehicle (EV) and hybrid electric vehicles (HEV) are becoming popular, and the number of production is rapidly increasing. The other type of electric vehicles, such as fuel cell electric vehicle (FCV), has also been introduced in the market. These vehicles are generally quieter than the conventional internal combustion engine vehicles (ICEV) particularly when they are travelling at lower speed. It is highly demanded to predict and evaluate of the environmental noise reduction effect by the growth of their population.

In Japan, the ASJ RTN-Model 2013[1] is widely used for the prediction and evaluation of road traffic noise. Recently the ASJ RTN-Model 2018 has been published

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as the latest prediction model as a report from the research committee of road traffic noise in the Acoustical Society of Japan, which are going to be published in English in the near future. In those models, A-weighted equivalent continuous sound level (L_{Aeq}) at the prediction point is calculated from the A-weighted sound power level ($L_{W\mathrm{A}}$) of the passing vehicles on the target road. The $L_{W\mathrm{A}}$ is given as a function of running speed for each type of vehicle and running condition.

In order to predict the noise reduction effect of electric vehicles, it is necessary to understand their $L_{W\mathrm{A}}$. Some studies on the sound power level of EV/HEVs [2, 3] have reported that the $L_{W\mathrm{A}}$ of EV/HEVs was 1 to 2 dB lower than ICEVs while they were driven at steady speed of 50 km/h. However, there is little knowledge about that in lower speed. Our research goal is to clarify the $L_{W\mathrm{A}}$ of electric vehicles running in lower speed.

2. MEASUREMENT

The measurements were carried out on flat straight roads with little acoustic obstructers around. Four sites were chosen to conduct the measurements; Ito Campus and Chikushi Campus of Kyushu University, Funabashi Campus of Nihon University, and University of Miguel Hernandez. Table 1 shows the measurement environment. Six measurements were carried from 2016 to 2017. Table 2 shows the measurement conditions. Test vehicles were six kind of passenger vehicles those were available in the market. The specifications of test vehicles are shown in Table 3.

Table 1 – Measurement environment.

	Site A.	Site B	Site C	Site D
Location	Kyushu Univ., Ito Campus (Fukuoka, Japan)	Kyushu Univ., Chikushi Campus (Fukuoka, Japan)	Nihon Univ., Funabashi Campus (Funabashi, Japan)	Univ. Miguel Hernandez. (Elche, Spain)
Road surface	dense asphalt	dense asphalt	dense asphalt	dense asphalt
Surrounding view and road surface				

Table 2 – Measurement conditions.

Date	Site	Background noise level $L_{\mathrm{Aeq,10s}}$ [dB]	Test vehicle(s)
2016.07.14	A	53.8 dB	EV
2016.10.12	C	41.4 dB	HEV1
2016.10.25	A	43.5 dB	EV HEV1
2016.11.24	D	44.3 dB	HEV1 HEV3
2017.05.16	A	38.2 dB	HEV2 FCV
2017.10.26	B	46.1 dB	ICEV

Table 3 – Specifications of test vehicles .

	EV	HEV1	HEV2	HEV3	FCV	ICEV
Model	Nissan LEAF	Toyota PRIUS	Toyota VOXY	Toyota AURIS	Toyota MIRAI	Honda STEPWGN
Weight (kg)	1,430	1,360*	1,610	1,400	1,850	1,650
Tire size	205/55R16	195/65R15*	195/65R15	225/45R17	215/55R17	205/60R16
Site	A	A, C, D	A	D	A	B

* Toyota PRIUS with 1,370 kg weight and 215/45R17 tire was used in the test at UMH

The measuring microphone was set at 1.2 m height and 2.0 or 7.5 m away from the center of the lane. The vehicle was driven to run at steady speed during the testing distance, as shown in Fig. 1.

The $L_{W\mathrm{A}}$ of passing-by vehicle is usually calculated using the following formula on the assumption that the test vehicle is an omnidirectional point sound source.

$$L_{W\mathrm{A}} = L_p + 20\log_{10} d + 8 \qquad (1)$$

Where L_p is obtained maximum level of A-weighted sound pressure level at the microphone d [m] away. Usually the distance d is 7.5m to ensure the assumption of omnidirectional point source. It is necessary, however, to shorten the distance d in consideration of avoiding the influence of background noise, because the noise emitted from the test electric vehicles are lower.

That means it is difficult to consider a test vehicle as an omnidirectional point sound source due to the shorter measurement distance. The measurement value may be influenced by interference of rolling noise from each tire. According to the literature[4], which examine similar problem with the larger vehicle whose length were comparable with horizontal distance to the microphone, the dispersion of $L_{W\mathrm{A}}$ prediction due to wheelbase length of larger vehicles could be reduced by using the square integration method[5].

Then, the $L_{W\mathrm{A}}$ were calculated by the square integral method. The energy average levels $\bar{L}$ of the sound pressure level while the vehicle passes through both sides l [m] of the PP' line were obtained. Then the $L_{W\mathrm{A}}$ were calculated by the formula (2).

$$L_{W\mathrm{A}} = \bar{L} + 20\log_{10} d + 8 + 10\log_{10}\left(\frac{\kappa}{\tan^{-1}\kappa}\right) \qquad (2)$$

Where $\kappa = l/d$.

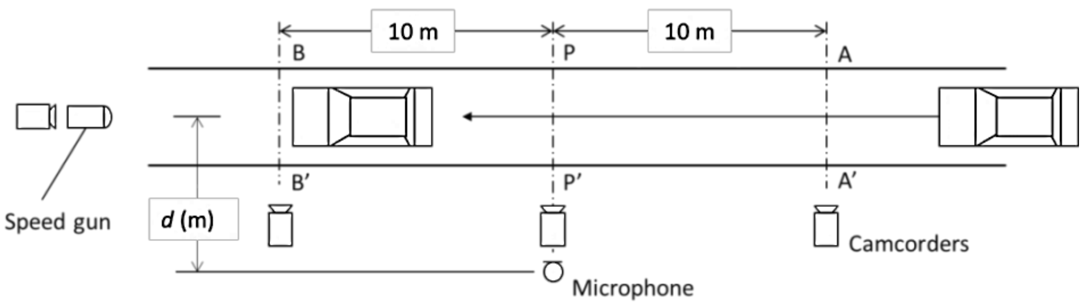

Fig. 1 – Measurement set-up (d =2.0, 7.5).

3. RESULT

3.1 Comparison on Measurement Methods

The L_{WA} was calculated using the square integral method as well as the maximum level method. To confirm the method, the differences between two calculation when the distance *d*=7.5, $\Delta L_{WA,7.5m}$ ($= L_{WAm} - L_{WAe}$) (L_{WAm}: power level calculated by the maximum level method, L_{WAe}: power level calculated by the square integral method), were examined by the test vehicles measured in the test site A. The results are shown in Table 3. The level with the maximum level method was slightly lower but negligible.

The differences between the distances (*d*=2.0 and 7.5), ΔL_{WAe} ($= L_{WAe,2.0m} - L_{WAe,7.5m}$) were examined and shown in Table 4. The calculated level from the measurement at *d*=2.0 were slightly underestimated. However, the deviations were not too large. In this paper, the L_{WA} calculated by square integral method at 2.0 m position were employed for following analysis.

Table 3 – Level difference between two methods ($\Delta L_{WA,7.5m}$)

	Average	S.D.
HEV1	-0.31	0.23
HEV2	-0.40	0.27
FCV	-0.67	0.67

Table 4 – Level difference between the measurement distance (ΔL_{WAe})

	Average	S.D.
HEV1	-1.55	0.32
HEV2	-2.71	0.49
FCV	-2.57	0.47

3.2 Speed Dependence of L_{WA}

Fig. 2 and 3 show the speed dependence of the $L_{WA}$of passing-by electric vehicles obtained by the square integral method using 2.0 m distance microphone. The dependence of a passenger car in steady and non-steady traffic flow section in ASJ RTN-Model 2013[1] are also shown in the Figures, hereinafter referred to as "ASJ-steady" and "ASJ-non-steady", respectively. Also the dependence of rolling noise contribution (L_{WR}) in CNOSSOS-EU[6] are shown in the Figures. With regard to the ASJ model, the although the steady traffic flow section is defined at the speed of 40 km/h or higher, in this analysis that is extended to 15 km/h.

The speed dependence of the L_{WA} of each test vehicle showed similar curve to the ASJ-steady and CNOSSOS-EU. The regression equation for each vehicle were estimated (see Table 5). In the CNOSSOS model, the coefficients are given for each 1/3 octave band. Here, equivalent equation was estimated by accumulating all bands and A-weighted correction. The coefficients of test electric vehicles were greater than the ASJ (=30) or CNOSSOS (=32.7), and not vary too large among the test vehicles. These suggest that the contribution of propulsion noise is negligibly small even in the slower speed range. It is suggested that the tier/road noise is dominant for the sound power level of electric passenger vehicles travelling slowly.

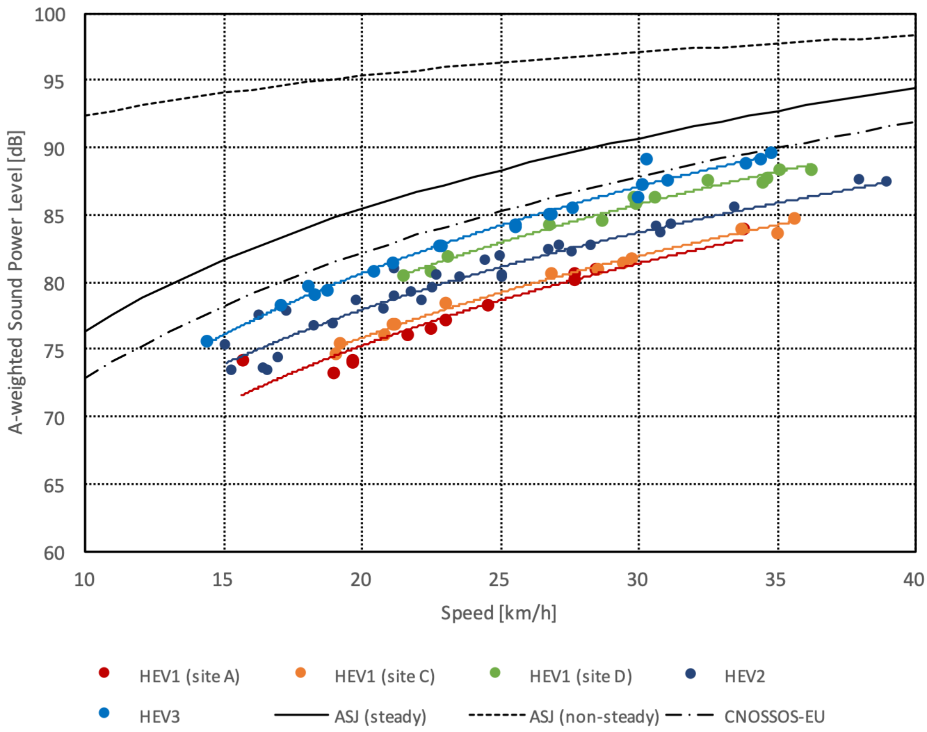

Fig. 2 – Speed dependence of L_{WA} (HEV)

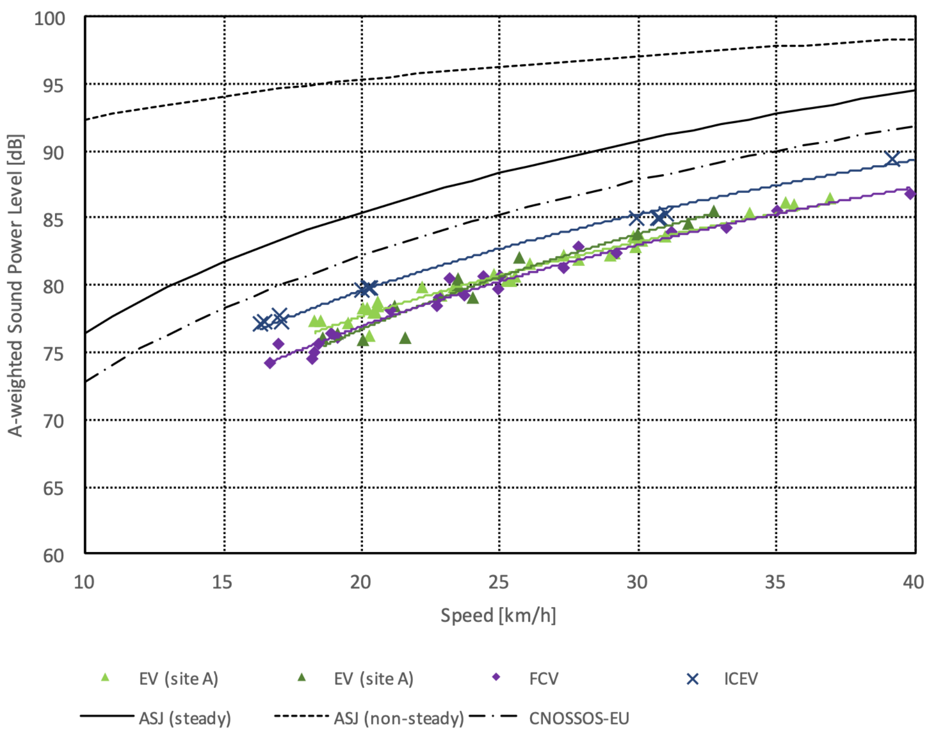

Fig. 3 – Speed dependence of L_{WA} (EV, FCV, and ICEV)

Table 5 – Regression equations for each test vehicle measurement and known models

	Site	Regression equation	Estimated L_{WA}	
			20 km/h	30 km/h
HEV1	A	$L_{WA} = 36.2 \log_{10} V + 28.8$	75.9	82.2
	C	$L_{WA} = 34.6 \log_{10} V + 30.2$	75.3	81.4
	D	$L_{WA} = 36.0 \log_{10} V + 32.6$	79.5	85.8
HEV2	A	$L_{WA} = 32.5 \log_{10} V + 35.6$	77.9	83.6
HEV3	D	$L_{WA} = 34.6 \log_{10} V + 36.4$	76.7	83.8
EV	A (1)	$L_{WA} = 31.4 \log_{10} V + 36.8$	77.7	83.2
	A (2)	$L_{WA} = 40.3 \log_{10} V + 24.3$	76.7	80.4
FCV	A	$L_{WA} = 34.4 \log_{10} V + 32.2$	76.9	83.0
ICEV	B	$L_{WA} = 32.6 \log_{10} V + 37.2$	79.6	85.3
ASJ RTN-Model 2013 (steady section)		$L_{WA} = 30 \log_{10} V + 46.4$		
CNOSSOS-EU (equivalent, A-weighted)		$L_{WA} = 32.7 \log_{10} V + 39.1$		

The constant terms of the regression equation of electric vehicles were from 24.3 to 36.8, which are lower than that of the ICE test vehicle. The estimated L_{WA} in 20 to 30 km/h speed range of electric vehicles were 2 to 4 lower than that of ICE test vehicle, except the HEV1 in test site D. The difference was 4.3 dB at a maximum. According to the previous reports[2, 3], the difference was around 2 dB in 50 to 60 km/h range. It is suggested that the difference of sound power between electric and conventional vehicles are wider and noticeable in the speed range blow around 40 km/h.

The L_{WA} obtained in the test site D were comparable with ICEV. The possible effect of road surface was considered. The comparison of L_{WA} of the test vehicle HEV1 measured in three different test sites shows that the result in site D was significantly higher but the regression coefficients were similar. As the reason, the difference of tier size and gross weight would be mentioned. However, the test vehicle FCV, which has the heaviest weight, didn’t show particular increase among the results in test site A. This suggests the important role of road surfaces.

Fig. 4 shows the comparison of relative A-weighted sound power levels of HEV1 in 1/3 octave bands among different test sites. All results show their peak at 800 to 1000 Hz. That coincide with the model spectrum provided by ASJ RTN-Model 2013. However, the results in site D show less power in lower frequency and higher kurtosis compared to those in site A and C. Although the road surfaces were dense asphalt in all test sites, the condition and grain size were different each other. More study of the effect of road surface on emitted road traffic noise is still important.

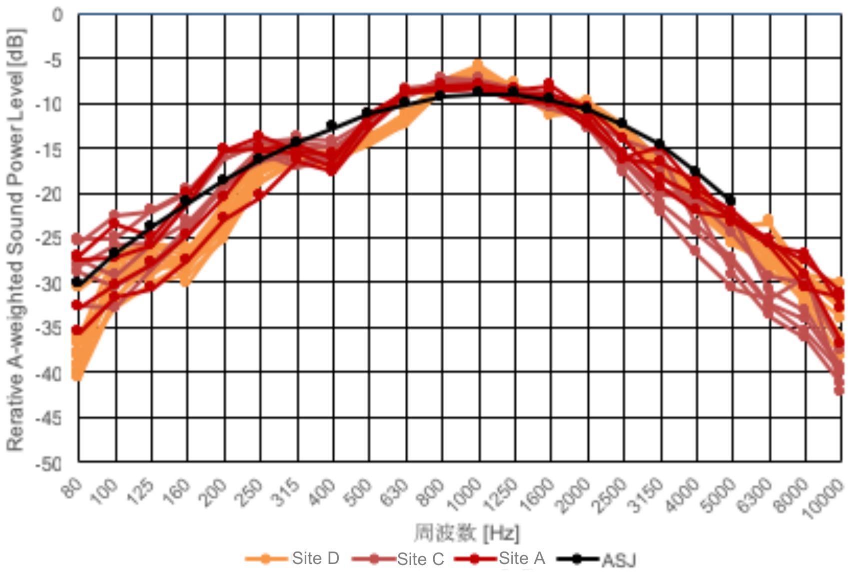

Fig. 4 – Comparison of relative sound power level of HEV1 among different test sites.

3.3 Difference of HEV's $L_{W\mathrm{A}}$ travelling with or without combustion engine

Some types of hybrid vehicles can be driven solely by electric motors without running internal combustion engine. Hereafter, the propulsion mode without running engine is referred to as EV-mode, while the propelled with combustion engine together is referred to as combination-mode.

Table 6 shows the comparison of $L_{W\mathrm{A}}$ of HEVs between EV and Combination modes. The estimated $L_{W\mathrm{A}}$ based on the regression equation were less than 0.4 dB and not significantly different between two modes.

Table 6 – Comparison of power level of HEVs between EV and Combination modes.

	Mode	Regression equation	Estimated $L_{W\mathrm{A}}$ 20 km/h	Estimated $L_{W\mathrm{A}}$ 25 km/h
HEV1 (site C)	EV	$L_{W\mathrm{A}} = 36.6\log_{10} V + 28.2$	75.8	79.4
	Combination	$L_{W\mathrm{A}} = 34.5\log_{10} V + 31.1$	76.0	79.3
HEV2 (site A)	EV	$L_{W\mathrm{A}} = 34.5\log_{10} V + 32.9$	77.8	81.1
	Combination	$L_{W\mathrm{A}} = 31.2\log_{10} V + 37.6$	78.2	81.2

3.4 Effect of AVAS on overall $L_{W\mathrm{A}}$

The acoustic vehicle alerting system (AVAS) is a designed device to create artificial noise in the speed range from 0 to 20 km/h. The UN-Regulation No.138 [7], which was published in 2016, introduces the minimum sound level, spectral characteristics, and frequency shift depending on the vehicle's speed. The AVAS designed under the previous guideline, which was published by Japanese ministry of land infrastructure and transportations in 2010, was installed on the test vehicles in this measurement. As a pilot examination, the effect of AVAS on relative A-weighted sound power level in 1/3 octave bands are shown in Fig. 5 and 6. The difference between with and without AVAS were not significant.

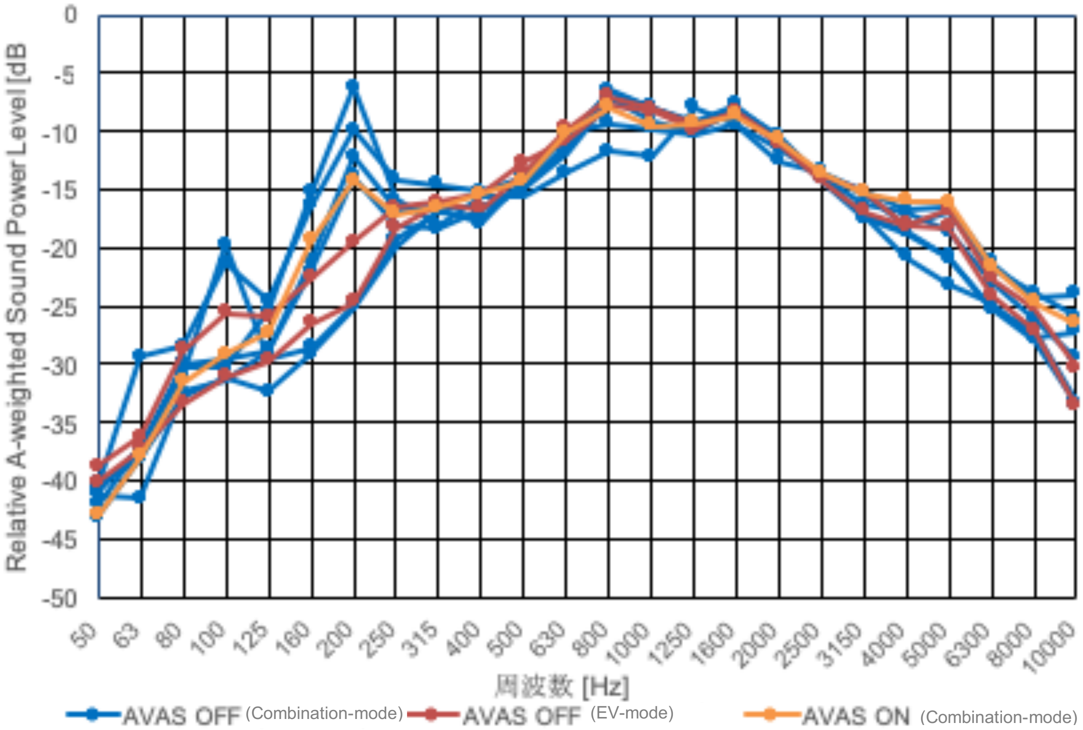

Fig. 5 – Relative L_{WA} of HEV2 with or without AVAS

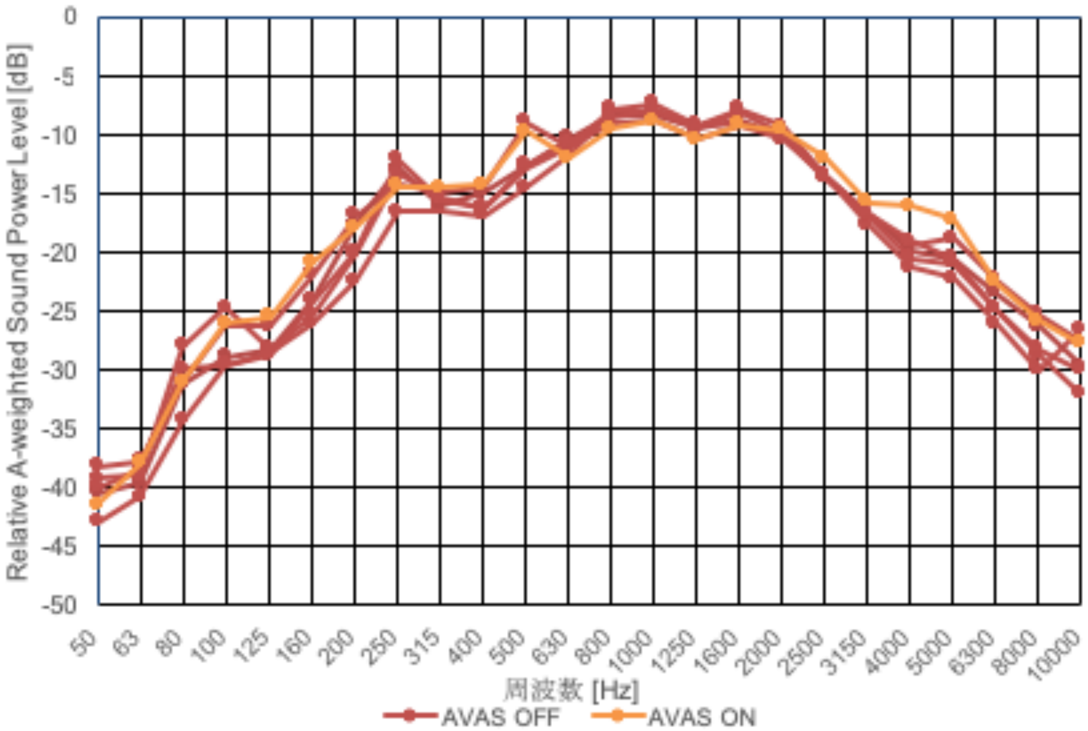

Fig. 6 – Relative L_{WA} of FVC with or without AVAS

4. CONCLUSIONS

In order to introduce electric vehicles into the noise prediction models, it is necessary to develop the model of the sound power level as the function of the vehicle speed. In this research, several measurements on sound power level (L_{WA}) were carried out on a dense asphalt pavement. Six kind of passenger vehicles; 3 HEVs, 1 EV, 1 FCV, and 1 ICEV; were employed in the test. The result showed that L_{WA} of test electric vehicles in 20 to 30 km/h speed range were 2 to 4 dB lower than the ICEV. Additionally, the comparison of L_{WA} between propulsion modes of HEVs and the comparison of the frequency analysis with/without AVAS were examined. The difference between propulsion modes and activation of AVAS was not significant on the noise emission.

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6. REFERENCES

1. Research Committee on Road Traffic Noise, the Acoustical Society of Japan, *"Road traffic noise prediction model ''ASJ RTN-Model 2013'': Report of the Research Committee on Road Traffic Noise,"* Acoust. Sci. & Tech., Vol. 36 (2), pp.49–108 (2015)
2. Miki Yonemura, Hyojin Lee, Shinichi Sakamoto, *"Survey of difference of sound power level between gasoline engine vehicles and hybrid/electric vehicles,"* Proc. Spring Meet. Acoust. Soc. Jpn., pp.971–972 (2016) (in Japanese).
3. Yasuaki Okada, Terutoshi Tajika, Shinichi Sakamoto, *"Road traffic noise prediction model "ASJ RTN-Model 2013" proposed by the Acoustical Society of Japan -Part 2: Study on sound emission of road vehicles,"* Proc. INTER-NOISE 2014, 536 (2014).
4. Yasuo Oshino, Shigeo Tasaki, Hideki Tachibana, *"The scatter of data caused by interference of tire noise in sound power level measurement of running road vehicles,"* J. Acoust. Soc. Jpn. (J), Vol. 46 (5), pp.397–402 (1990) (in Japanese).
5. H. Tachibana, *"Study on the sound level measurements for road vehicles,"* Tech. Rep. Noise Acoust. Soc. Jpn., N-85-05-3 (1985) (in Japanese).
6. Stylianos Kephalopoulos, Marco Paviotti, Fabienne Anfosso- Lédée, *"Common Noise Assesment Methods in Europe (CNOSSOS-EU),"* JRC Reference Reports (2012).
7. UN Regulation No. 138, *"Uniform provisions concerning the approval of Quiet Road Transport Vehicles with regard to their reduced audibility"* (2016).