International Refereed Journal of Engineering and Science (IRJES)
ISSN (Online) 2319-183X, (Print) 2319-1821
Volume 13, Issue 2 (Mar.-Apr. 2024), PP. 19-25

Beyond Decibels: Analyzing the Differential Impact of Electric and Combustion Engine Vehicle Noise

Harald LERCH, *Dpt. of Machine Design, Faculty of Mech. Engineering, University of West Bohemia, CZ*
Matthias BERCHTOLD *(Co-Author), INGCONSULT.AT INGENIEURE GmbH, Innsbruck, Austria*

Abstract — *Regarding the Economic Commission for Europe of the United Nations Regulation No 51 (UN/ECE R51) – Uniform provisions concerning the approval of motor vehicles having at least four wheels with regard to their noise emissions, there are limits to the sound level of vehicles. The UN/ECE R51 defines the driving-(motion) and stationary-noise level for vehicles. The UN/ECE R51 regulation defines the sound level limits and how those sound levels are measured. [1]*

An acceleration limit of 2m/s² is specified in the UN/ECE R51. In reality, however, it has been shown that vehicles accelerate faster than 2 m/s², e.g. from traffic lights in city centers, especially to show off, or when overtaking on open roads. The noise emission of fast accelerating cars are higher than the UN/ECE R51 specifies. This paper is intended as an impetus to conduct further research to understand whether and how road noise could be harmful to the human organism and if there is a difference between internal combustion engine vehicles (ICEV) and electric vehicles (EV). In total three different test procedures are performed. The 1st test procedure with const. velocity, the 2nd with max. 2m/s² (regarding to UN/ECE R51) and the 3rd test procedure is made with maximum possible vehicle acceleration. Especially the difference between ICVs and EVs in noise emission will be highlighted in this paper.

However, due to too much traffic, especially in larger cities, the frequency range of the different sound levels of EVs and ICEVs are not considered. According to [2] almost 60 million people in the EU are exposed to road traffic noise levels above 55 db and approximately 11 million adults were highly annoyed by road traffic noise, which could even cause death, e.g. from ischemic heart disease [2]. Due to urbanization more and more people are exposure to environmental noise. In Europe people experience noises from a variety of different sources, such as road traffic, railway and aircraft, whereby road traffic noise is the main source of environmental noise. [3]. Regarding to [4] there is a relationship between environmental noise, in particular traffic noise and health effects, whereby long-term exposure to environmental noise leads to ischemic heart disease and can cause death.

Keywords— *noise emssions, EVs, ICVs, FFT, acceleration, UN ECE R51, driving noise, motion noise, sound level, traffic noise*

Date of Submission: 09-03-2024 Date of acceptance: 23-03-2024

I. OBJECTIVE

This paper evaluates the difference between the UN ECE R51 regulation, with a maximum of 2m/s² and the reality with accelerations > 2m/s². Especially the difference in noise emissions between ICEVs and EVs are investigated. Furthermore, a Fast Fourier Transformation (FFT) of the recorded sound was made, to evaluate the difference in noise emission and the difference in frequency levels.

Regarding to UN/ECE R51 for electric vehicles only a driving measurement needs to be performed, due to to the fact, that EVs emit no noise, when they are stationary. For internal combustion engine cars, a stationary and a motion noise level measurement needs to be performed. For the driving noise, two different measurements need to be performed. One is performed with constant velocity of 50 km/h and a second one is performed with fully pushed through throttle on a distance of 20 m, with a maximum acceleration of 2 m/s². In these tests, only the maximum noise values, measured in dB, are considered. The test set-up is shown in chapter II Measurements. Two comparable vehicles (Porsche Cayenne E-Hybrid and Tesla Model Y) were used for the test. One is an internal combustion engine vehicle and the other one is an electric vehicle. Both cars have approximately the same specifications.

A 3rd test had been added to the test procedure of the UN/ECE R51. This 3rd test procedure uses the same test set up as test procedure 1 and 2, but both vehicles will accelerate as fast as possible. For all tests, the same set-up had been used, see figure 1. The paper evaluates the different FFT-outcomes and compares the mean values between both test vehicles of each test procedure.

Furthermore, this paper intended as an impetus to figure out which frequencies having harmful effects to the human body. Especially in developing a motorcycle sound engineering plays a major role, to recognize the brand of a motorcycle only by hearing it. Eventually sound engineering could be also an approach to reduce traffic noise.

II. MEASURMENTS

For the measurements two types of cars, with almost the same specifications had been chosen. Both cars have almost the same driving characteristics and belong to the same vehicle category:

1. Tesla Model Y
2. Porsche Cayenne E- Hybrid

Comparison between the two different cars:

Vehicle	Tesla Model Y	Porsche Cayenne E-Hybrid
Type	SUV	SUV
Drive unit	Electric	Gasoline and Electric
Engine power [kW]	378	310
Transmission	Automatic	Automatic
Driving noise target value [dB(A)]	68	68
Acceleration 0 to 100 km/h	5,0	4,9
Year of construction	2023	2023
Net weight [kg]	1989	2446
Tire size	255/45R19 on 9,5Jx19	285/35 ZR22 on 10Jx22
Max. possible acceleration	5,1	5,3

Table 1 – Overview about the test cars

The vehicles driving noises had been recorded with a sound level meter. To validate the measurement, the specified driving noise levels must be observed and need to be at the same sound level as the target values. The target values were taken from the type certificate of each car.

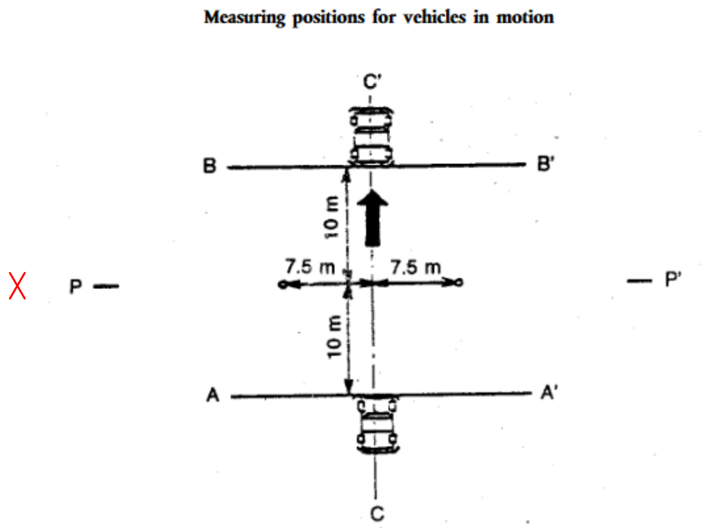

Figure 1: Test set up

The tests were carried out in accordance with UN/ECE R51. Figure 1 shows the test set up. A street with no abstacles in the immediate vicinity of the test track was choosen. Between line AA' and BB' are 20 m. The microfone for recording the noise and the sound meter was placed in the middle of distance AA' to BB' (red cross), exactly 7,5 m away from the vehicles centerline at a height of 1,2 meter. The following environmental conditions prevailed at the time of measurement.

Test date	27.02.2024
Temp. [C°]	10
Humity	80%
Windspeed [m/s]	1-2
Weather condition general	Cloudy
Asphalt temperatur [C°]	7
Asphalt conditions	dry

Table 2 – environmental conditions

Before the test, the vehicles tire pressure and tread depth had been checked, according to the user manuel of the different car. The tests had been conducted with the engine at operating temperature. Due to the fact, that the measruemtns were performed on 27.02.2024, each car was equipted with winters tieres.

Three different tests had been performed:
1. The first test was with a constant velocity of 50 km/h, between line AA' and BB'. This test had been performed with the cruise control turned on, to have a constant velocity. The velocity was controlled by using a calibrated GPS measuring device.
2. The second test was with the maximum possible acceleration, starting at a velocity of 50 km/h. When the car reaches line AA' the throttle had been fully pushed through, to reach the maximum acceleration. For the Porsche with automatic transmission, the standard set up was choosen.
3. The third test was with acceleration of max 2 m/s² between line AA' and BB'. The car reaches line AA' with a velocity of 50 kim/h. When the vehicle reaches the line AA' the throttle had been fully pushed through. For the electrtic vehicle a maximum acceleration of 2 m/s² was given in UN/ECE R51. The Porsche with transmission had been measured in the gear (3rd gear), where the accelaration was < 2m/s². The acceleration values of the vehicles had been recorded as well (see table 1).

Test plan overview		
Test procedure	**Velocity at AA'**	**Acceleration between AA' to BB'**
1	50 km/h	0 m/s² | const. velocity
2	50 km/h	Max. possible
3	50 km/h	≤ 2 m/s²

Table 3 - Test plan overview

III. RESULTS

To validate the measurements, the maximum sound level values from the 3rd test procedure were used. Test procedure 3 corresponds exactly to the measurement procedure for determining the driving noise. The sound level values need to be within the driving noise target values (see table 4). The difference between the actual values and the measured values can be attributed to measurement tolerance.

Vehicle	Tesla Model Y	Porsche Cayenne E-Hybrid
Driving noise target value [dB(A)]	68	68
Driving noise actual value [dB(A)]	67,5	68,4

Table 4 – Comparison between target and actual driving noise values

All three test procedures had been evaluated and the two cars had been compared to each other. The x-axis is the frequency in [Hz] and the y-axis is the sound level in [dB(Sound Pressure Level)]. For the evaluation a fast Fourier transformation was performed.

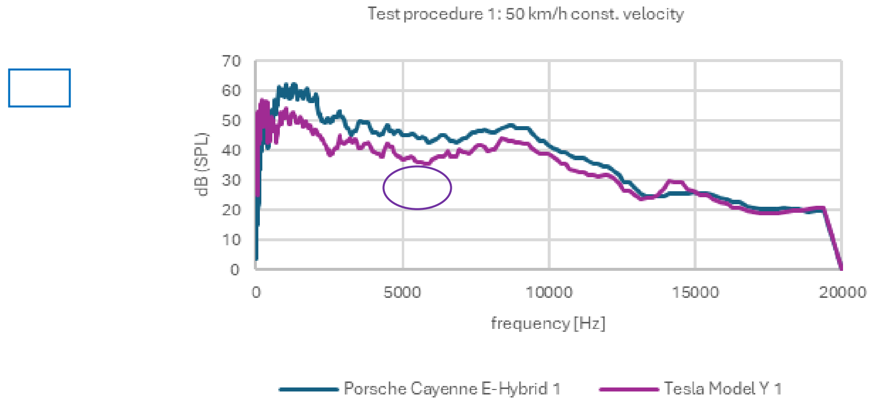

Figure 2: Evaluation of test procedure 1

As can be seen in Figure 2, with a const. velocity of 50 km/h and 0 m/s² acceleration the Tesla Model Y emits less noise than the Porsche Cayenne E-Hybrid. The maximum sound level of the Porsche is 62,3 dB(SPL) and the max. values of the Tesla is 56,9 dB(SPL) (see also figure 7).

The frequency range 1000 to 2000 Hz for the Porsche (blue frame) is characteristic for an ICEV. According to [5] the main sound sources for an ICEV are crank drive, valve train, combustion forces, auxiliary units, exhaust system, fan, and much more. All those sound sources occur in a frequency field of 20 to ca. 2000

Hz. Sound sources which occur between 0 to 1000 Hz are mostly emitted by structure-borne sound. Above 1000 Hz sound sources emit there sound mostly by airborne sound.

At the frequency range of 13,5 to 15 kHz (purple highlighted) the Tesla is around 5 dB(SPL) louder than the Porsche. This could come from the inverter, which produces a pulse width modulation signal (PWM) for the electric engine.

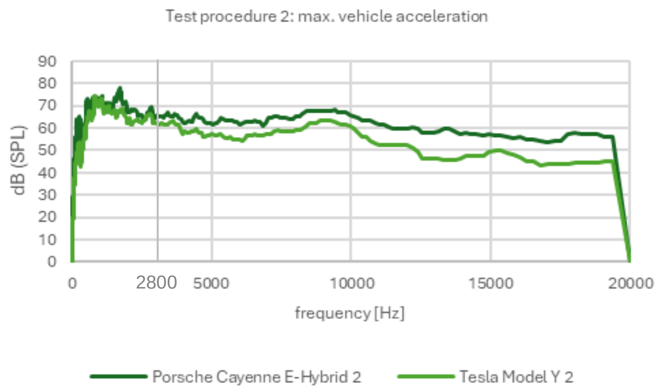

Figure 3: Evaluation of test procedure 2

As can be seen in figure 3, in average (mean value observation) the Porsche is around 6,5 dB(SPL) louder than the Tesla during max. acceleration. The max. sound level for the Porsche is 78 dB(SPL) and for the Tesla is 74,6 dB(SPL), whereby the delta is 3,4 dB(SPL) (see also figure 7). The Porsche has its max. sound level at a frequency of 1690 Hz.

Starting at a frequency around 2800 Hz the Tesla is in average (mean value observation) 7 dB(SPL) more quiet than the Porsche

For a better interpretation for lower frequencies at test procedure 2, figure 4 shows the evaluation only to a frequency of 4000 Hz.

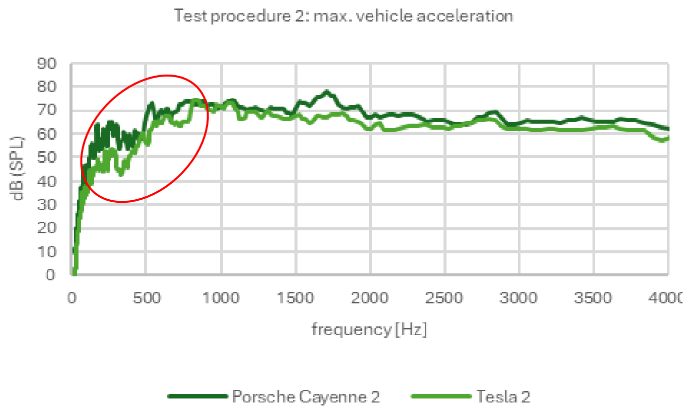

Figure 4: Evaluation of test procedure 2 - frequency range from 0 to 4000 Hz

Over the whole frequency range, the Porsche is louder than the Tesla. Especially for a frequency range between 60 to 800 Hz the Porsche is in average (mean value observation) 8 dB(SPL) louder (red highlighted).

Due to the fact that this paper evaluates the difference between the actual UN ECE R51 measurement method with max. 2 m/s² and the max. possible vehicle acceleration, the mean values of test procedure 2 are divided into the different frequency ranges (see figure 5).

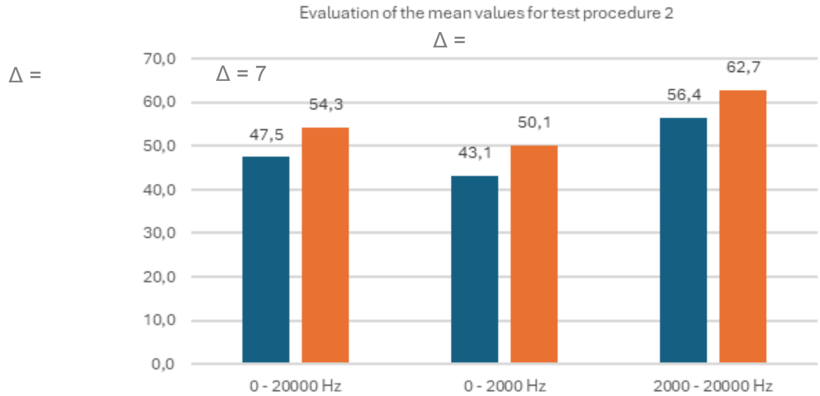

Figure 5: Evaluation of mean values for test procedure 2
(blue is Telsa, orange is Porsche)

Figure 5 shows the difference for the mean values for test procedure 2. The chart is divided into three different categories: 0 to 20000 Hz, 0 to 2000 Hz and 2000 to 20000 Hz. In average (mean value observation) the Porsche was 6.8 dB(SPL) louder than the Tesla.

Especially in the frequency range of 0 to 2000 Hz, the Tesla was 7 dB(SPL) more quite than the Porsche. This is the frequency range, where most of the ICEV sounds occur (see [5]) and where the biggest divergence between Tesla and Porsche had been evaluated.

For frequencies above 2000 Hz, the difference between the Porsche and the Tesla decreases to a mean value of 6.3 dB(SPL).

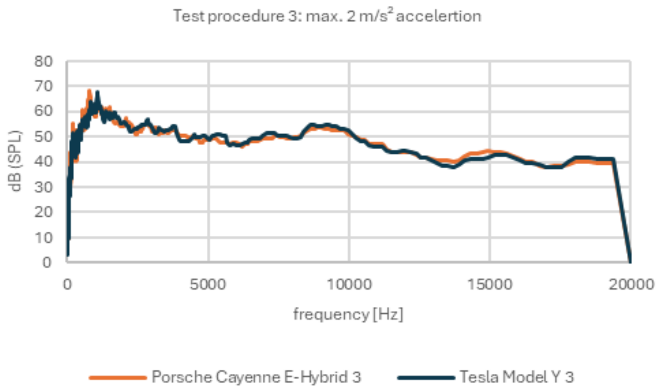

Figure 6: Evaluation of test procedure 3

As can be seen in figure 6, for a max. acceleration of 2 m/s² both vehicles almost have the same sound level over the frequency range between 0 to 20000 Hz. Test procedure 2 is the official test procedure to measure the driving noise. In table 4 the max. values (actual driving noise values) of figure 6 are already mentioned and compared to the target values of each car. The difference between actual driving noise and target driving noise can be attributed to measurement tolerance.

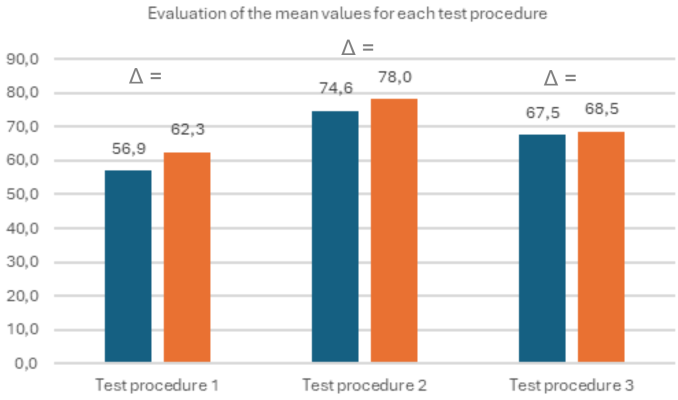

Figure 7: Evaluation of mean values for each test procedure
(blue is Telsa, orange is Porsche)

As can be seen in Figure 7, the mean value observation of each test procedure is lower for the EV than for the ICEV. Especially for test procedure 1 the divergence between Tesla and Porsche is quite high with a difference of 5,4 dB(SPL). For test procedure 2 its around 3.4 dB(SPL) and for test procedure 3 it's the least value of 1,0 dB(SPL). The least divergence between Porsche and Tesla at test procedure 3 could lead from the fact, that with increasing velocity the rolling noise of the vehicles increases to a decent amount. The acceleration is less than 2 m/s² and therefore the engine and exhaust sound of the ICEV is lower and the rolling noise is louder.

From this one could deduce that EVs are generally quieter than ICEVs, but this needs to be confirmed by several tests with different vehicles. Especially by velocities higher than 50 km/h and an acceleration of max. 2 m/s² it would be interesting to know, if the divergence between EVs and ICEVs will be neglectable.

IV. CONCLUSION

In comparison between an ICEV and EV the EV emits less noise to the surrounding environment than the ICEV. At a constant velocity of 50 km/h (test procedure 1) in average 5,4 dB(SPL) less and at max. possible acceleration (test procedure 2) in average less than 6,8 dB(SPL), than the ICEV. It's important to mention, that a sound level increase of 10 dB corresponds to a doubling of the perceived noise.

According to test procedure 3, for a max. acceleration of 2 m/s², both cars emit almost the same driving noise to their surrounding environment. This could be, because by increasing velocity, the rolling noise of vehicles is increasing to a decent amount.

Due to the fact, that the EV in general emits less driving noise, especially in the frequency range between 0 to 1000 Hz, where perceived noise, such as droning, humming, roughness, sawing (see [5]) occur, it would be also interesting to evaluate, if EVs emit less noise in interior spaces, when the windows are closed.

Furthermore, it's important to note that the maximum sound levels in dB(SPL) for driving and stationary noise, as determined in UN/ECE R51, are only absolute values. The regulation does not address the composition of the measured noise. Therefore, it is crucial to break down driving noises into the frequency range of 20 to 20,000 Hz, which represents the human hearing frequency range. Particularly, low frequencies generated by internal combustion engines have longer wavelengths, allowing them to travel more easily through different materials such as windows compared to high frequencies with shorter wavelengths. This noise that reaches people can cause mental and health problems.

Primarily, it is the low frequencies emitted by vehicles with combustion engines compared to electric vehicles that are not accounted for by standardized sound levels. These frequencies are what disturb people when considering traffic congestion and are also audible within residential buildings.

This paper serves as a catalyst for further research. Two comparable cars were used as examples for the measurements; however, these cars represent only a small fraction of the vehicles on our roads. In the future, we aim to measure more cars to improve the data situation.

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