Article citation info:
Cebulska W, Hadrys D. Comparison of vibration emissions in electric and conventional cars. Combustion Engines. 2025;202(3):74-80. https://doi.org/10.19206/CE-204690

Wioletta CEBULSKA
Damian HADRYS

Combustion Engines
Polish Scientific Society of Combustion Engines

Comparison of vibration emissions in electric and conventional cars

ARTICLE INFO

Received: 22 November 2024
Revised: 5 May 2025
Accepted: 5 May 2025
Available online: 4 June 2025

Currently, great importance is attached to the issue of environmental protection, also in the context of the impact of transport on the environment. Limited fossil resources, climate change, and global warming are driving the automotive industry towards more efficient and sustainable solutions. These problems are driving car manufacturers to use new technologies and alternative drive systems. Examples of such vehicles are electric cars (EV) and hybrid cars (HEV or PHEV). The issue of the impact of using these means of transport on the emission of pollutants other than exhaust gases is important. An example of such emissions is vibrations. Cars with conventional drive generate vibrations from the operation of the combustion engine. All vehicles, both conventionally and alternatively driven, emit vibrations as a result of the operation of the drive system, suspension system, and interaction of tires with the road surface. Vibrations also arise from unevenness of the road surface. At first glance, it seems that vibrations are lower when driving an electric car. In this article, vibration measurements were performed inside an electric vehicle and a conventionally driven vehicle in urban and highway conditions.

Key words: *vibration emission, electric cars, electromobility, vibration measurements*

1. Introduction

Noise and mechanical vibrations accompany the operation of vehicles. Vibrations are a process in which physical quantities are variable as a function of time. Vibrations induced by a source are propagated by wave motion. These waves are transmitted through different media at different speeds, as a result of which kinetic energy (Ek) is converted into potential energy (Ep) and vice versa. Mechanical vibrations, the frequency band of which is in the range of 0.1–100 Hz, have an adverse effect on the human body. They are divided into shocks (changes in position to which the body reacts actively) and vibrations (the body reacts passively through the nervous system and organs). Exposure to vibrations can be short-term, in which the negative functional effects disappear after the vibrations cease, or long-term, causing health effects.

Vibration emissions in combustion cars are mainly due to the operation of the combustion engine, which generates vibrations during the combustion of the fuel mixture. These vibrations are transmitted by the drive system (gearbox, drive shaft) and the exhaust system. Vibrations can also be amplified by the operation of turbochargers, mufflers, and unevenness in the balance of moving elements, such as pistons and crankshaft.

In electric cars, vibration emissions are much lower because the electric engine operates more smoothly, without combustion processes and pistons. The lack of a gearbox eliminates jerks and additional sources of vibration. The main vibrations can come from small elements, such as engine bearings, cooling system fans, and road irregularities [1, 4, 11, 12].

2. Vibration measurements

Noise and mechanical vibrations accompany the operation of vehicles. Vibrations are a process in which physical quantities vary as a function of time. The basic quantities describing mechanical vibrations are displacement, vibration velocity, and vibration acceleration. The most common way to assess the effect of mechanical vibrations on the body is to use vibration acceleration values. A vibration signal may contain one component with a specific frequency (sinusoidal vibrations). However, complex vibrations consisting of many sinusoidal components are most common [7–9].

Due to the impact of vibrations, they can be divided into local vibrations (transmitted by limbs) and general vibrations (vibrations with a general effect). Whole-body vibrations refer to vibrations transmitted to the whole body. These vibrations can lead to health problems such as back pain, fatigue, and balance disorders. Reducing exposure to whole-body vibrations requires the use of appropriate shock-absorbing seats and ensuring an ergonomic work environment that minimizes the negative effects of mechanical vibrations. In local vibration measurements, based on the effective values of weighted vibration accelerations obtained by the meter during measurements, measured in all planes (x, y, z), the value of the vector sum of effective vibration accelerations is calculated according to formula (1):

$$a_{hvi} = \sqrt{a_{hwxi}^2 + a_{hwyi}^2 + a_{hwzi}^2} \quad (1)$$

where: a^2_{hwxi}, a^2_{hwyi}, a^2_{hwzi} – effective weighted vibration acceleration values, m/s^2, a_{hwi} – value of the vector sum of effective weighted vibration accelerations, m/s^2.

In the context of general vibrations, instead of the vector sum of the vibration acceleration, the dominant component is determined from the 3 planes x, y, and z. This means that the subsequent indices are determined for one dominant plane. Depending on which plane (x, y, or z) was selected as the value for evaluation, it should be multiplied by the appropriate factor: 1.4 for the x and y axes and 1 for the z axis. The calculation of the maximum value is determined by formula (2):

$$a_{wmax} = \max\{a_{wl1}, a_{wl2}, \ldots a_{wln}\} \quad (2)$$

where: a_{wln} – selected highest value from 3 measurement planes (x, y or z), m/s^2, a_{max} – value of the vector sum of effective weighted vibration accelerations, m/s^2.

During vibration measurement, physical quantities are measured: acceleration, velocity and displacement of mechanical vibrations. For each of these values, the vibration amplitude can be given. This will be the difference between the lowest and highest momentary vibration level, half of this value. However, amplitude is not the most popular vibration measure. The most commonly used value is described as RMS. In the analysis of vibration signals, this is the most popular numerical value describing the average "vibration level" of a given machine, it is the so-called "effective value" of the signal.

The RMS indicator simply estimates the value of the vibration level independently of the amplitude value. The square of the signal value in the formulas for energy, power and RMS of the signal is important not only because of the negative values of the signals but also because of the possibility of analogous calculations in the frequency domain [5, 6, 14].

The interpretation of vibration data in the time domain (amplitude plotted against time) is limited to a few parameters in determining the vibration level: amplitude, peak value, and effective value, which are identified in the sinusoidal waveform. The RMS value is generally the most useful because it is directly related to the energy level of the vibration. Vibration is an oscillatory motion, so most vibration analyses aim to determine the rate of this oscillation or frequency. The number of times a full cycle of motion occurs in one second is the vibration frequency and is measured in Hz. For simple sinusoidal waves, the vibration frequency can be determined from observing the time domain waveform. When different frequency components and noise are added, spectrum analysis is necessary to obtain a clearer picture of the vibration frequency. In order to correctly determine the frequency spectrum, signal sampling is used. This is the number of samples taken in 1 second. The higher the sampling rate, the more accurately the signal is recorded [5, 6, 11, 16].

3. Impact of vibrations

Exposure to vibrations can be short-term, in which the negative functional effects disappear after the vibrations stop, and long-term, causing disease effects. Short-term exposure to vibrations can cause functional discomfort (e.g. motion sickness), irritation, excessive fatigue, insomnia and disruption of movement coordination. Research results show that exceeding 0.25 m/s^2 of the effective value of low-frequency vibration acceleration in the range of 0.1–0.315 Hz in the vertical direction causes undesirable symptoms [16, 18, 19, 21].

Prolonged exposure to vibrations can cause disorders of the organs and nervous centers. General fatigue, decreased efficiency, and reduced psychophysical efficiency occur. Disorders of the skeletal and joint systems in the cervical and lumbar spine, as well as shoulder, hip, and knee joints, occur. As a consequence, this can cause muscle and joint pain and spine ailments in all of its sections. Vibrations with frequencies corresponding to the natural vibration frequencies of internal organs are a major danger, as they can induce resonant vibrations of the organs, disturbing the temporary functioning of the body. Vibrations have a mechanical effect on the eyeballs, causing the image in the retina to shift, which manifests itself in the impression of a blurred image, deterioration of visual acuity, and difficulties in locating objects in space [2, 3, 6, 17]. The ISO 2631–1:1997 standard specifies comfort levels depending on the value of vibration acceleration in m/s^2 [16]:

- comfortable – below 0.315
- slightly uncomfortable – from 0.315 to 0.63
- quite uncomfortable – from 0.5 to 1
- uncomfortable – from 0.8 to 1.6
- very uncomfortable – from 1.25 to 2.5
- extremely uncomfortable – above 2.

3. Vibrations in electric vehicles

In vehicle operation, the greatest impact on vibrations during driving is the wheel contact with the road surface, with additional vibrations from the drive system and the drive unit. Factors inducing ground vibrations include changes in the contact forces between the vehicle wheel and the road surface, the reaction of the moving vehicle to geometric changes in the road surface, the vehicle's reaction to unevenness and momentary wheel lift-off states, forces resulting from wheel imbalance, as well as the air wave generated during vehicle movement [7–10]. Vibrations generated during driving are transferred to the person through the seat and platform, as well as through control elements such as the steering wheel. The excitations are transferred through the suspension to the vehicle body, then to the driver's and passenger seats. The seat should therefore provide adequate comfort and limit the impact of mechanical vibrations [10, 12, 14].

Vibrations emitted by a combustion engine vehicle seem to be greater than in the case of an electric vehicle, because they have an additional factor generating vibrations in the form of an internal combustion engine, as well as a gearbox and an exhaust system. It is believed that in electric vehicles, these vibrations are much smaller due to the lack of an internal combustion engine and other systems and rotating elements that emit vibrations. In the case of hybrid vehicles, the sources of vibrations are the same as in the case of internal combustion and electric vehicles. However, the issue of vibration emission while driving is different. These vibrations are caused by the work of the suspension system, shock absorption, and the cooperation of the tire with the road surface. They mainly depend on the type and construction, as well as the wear of the wishbones, shock absorbers, springs, wheel balance, and the type of tires and the condition of the road surface. It seems that vibrations in cars with conventional drives and with alternative drives while driving are similar [7–10, 19, 20]. The frequencies of vibrations emitted by electric and internal combustion engines differ depending on their design, rotational speed, and type of work. Combustion engines can emit vibrations in a wide range of frequencies, usually from a few Hz to several kHz. Lower frequencies (around 20–100 Hz) are associated with engine vibrations and vibrations resulting from the operation of the drive unit. Higher frequencies (up to several kHz) can occur as a result of various processes, e.g. exhaust system vibrations. Electric motors also emit vibrations in the range of several Hz to several kHz, but have different characteristics. The operating frequency of an electric motor is related to the supply frequency, for example, 50 Hz or 60 Hz for AC motors. Vibrations can be generated by the rotation of the rotor, which leads to vibrations in the range of about 20 Hz to 1 kHz [12, 13, 20–22].

4. Equipment and research subject

The vibration measurement system Simcenter SCADAS XS was used in the vibration tests. This is an analyzer that, thanks to the data acquisition template, can operate as a stand-alone device. Depending on the needs of the SCADAS XS, it can be wirelessly controlled from a tablet using the Simcenter Testlab Scope App. In these tests, this application was used to measure and record data. The application allows for configuration, starting, or stopping data acquisition [14]. The measuring device, together with the seat vibration transducer, is shown in Fig. 1, while the technical data are in Table 1.

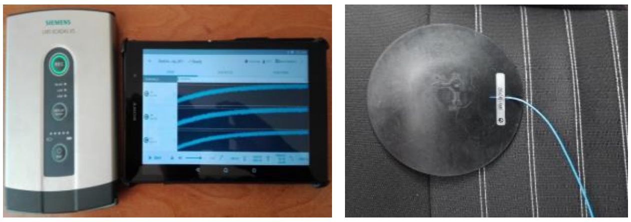

Fig. 1. Siemens LMS SCADAS XS vibration measurement system with data acquisition device – left side, three-axis seat cushion – right side

Table 1. Technical parameters of the Siemens LMS SCADAS XS vibration measurement system [17]

Feature	Value
Control	Wireless from a tablet app
Sampling	50 kHz per channel
Sensitivity	For a seat-mounted vibration transducer: 100 mV/g
BNC connector	For microphones or single-axis accelerometers
LEMO connector	For single cables (with multiple cables inside) that allow three channels of a triaxial accelerometer to be connected
CAN-bus	Controller Area Network (CAN) for reading digital bus from built-in vehicle sensors

Fig. 2. Conventional drive car Dacia Sandero

The objects (Fig. 2) of the research are two passenger cars. A conventionally powered car of the Dacia Sandero III brand with a 1.0 Tce turbocharged petrol engine with an output of 67 kW. An electric car of the Dacia Spring brand with a synchronous motor with a permanent magnet, with an output of 33 kW. Both vehicles were manufactured in 2021 and had Crossover bodies.

Table 2. Technical data of the Dacia Sandero [13]

Model	Dacia Sandero III Hatchback
Drive	Conventional
Engine	1.0 Tce petrol turbocharged
Displacement	999 cm^3
Engine power	67 kW, 90 HP for 4600 rpm
Torque	160 Nm for 2100–3750 rpm
Drive	Front axle
Range	962 km
Current weight	1152 kg
Year of production	2021

Fig. 3. Electric drive car Dacia Spring

Table 3. Technical data of the Dacia Spring [13]

Model	Dacia Spring Crossover Electric
Drive	Electric
Engine	Permanent magnet synchronous
Engine power	33 kW, 45 HP for 3000–8200 rpm
Torque	125 Nm for 500–2500 rpm
Drive	Front axle
Battery	lithium-ion
Gross battery capacity	27 kWh
Charging time socket/fast	13 h/1h
Range	230 km
Own weight	920 kg
Year of production	2021

5. Research

5.1. Vibration measurements on site

Vibration measurements using the Siemens vibration measurement system were carried out in the vehicle operation laboratory at the Faculty of Transport and Aeronautical Engineering of the Silesian University of Technology. During the tests, the cars were placed on a lift. The measurements were taken using a seat transducer placed on the driver's seat (general vibrations) in three axes, X, Y, and Z. In the X axis, values were measured along the vehicle axis, in the Y axis transversely to the vehicle axis, while in the Z axis, vertical vibration values. During vibration measurements, the overall vibrations affecting the driver through the seat while driving were recorded. This measurement was based on an analysis in accordance with formula (2), which describes the method of assessing human exposure to vibrations in accordance with applicable standards. The tests were carried out in the vehicles while the driver was engaged at a speed of 20 km/h. Each time, 10 measurements were taken, each lasting 5 seconds. The sampling frequency was 51,200 Hz. Example time courses and frequency characteristics were presented in the form of graphs

4 to 5. The collective results of the effective value of vibration acceleration are presented in Fig. 6.

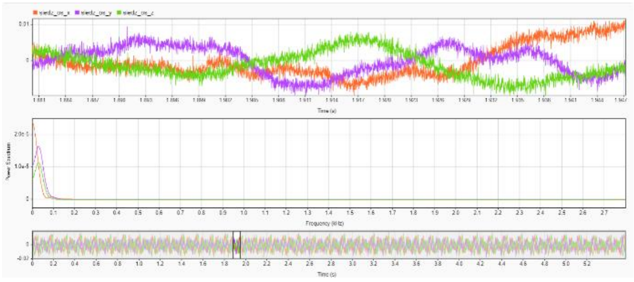

Fig. 4. Time course and frequency characteristics of the acceleration of vibrations of a conventionally driven car transferred to the driver (general vibrations) during tests at the test stand

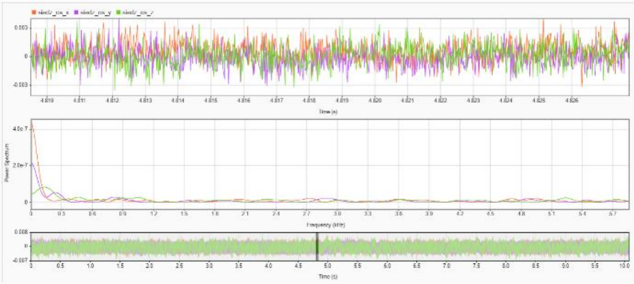

Fig. 5. Time course and frequency characteristics of vibration acceleration of an electric car transferred to the driver (general vibrations) during tests at the test stand

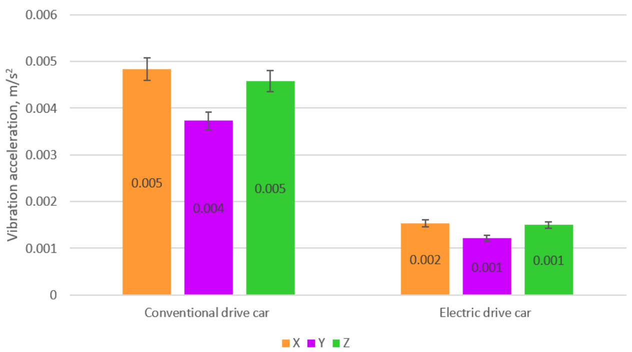

Fig. 6. Effective values of vibration acceleration in the X, Y, Z axes in vehicles measured on the driver's seat (general vibrations) during bench tests

Vibration measurements on the driver's seat showed that the lowest effective values of general vibration acceleration were recorded in the electric car (0.0021 m/s^2). General vibrations transferred to the driver during the operation of the combustion engine amounted to 0.0067 m/s^2. The vibration acceleration values were similar in all axes.

Vibrations in a combustion car have a higher level, with dominant frequencies below 0.5 kHz. They result mainly from the operation of the engine, drive system, and resonance of mechanical elements. In an electric car, vibrations are smaller, and their main band is below 0.4 kHz, which may be related to the operation of the electric engine and transmission. In short, combustion cars generate more complex vibrations, while electric cars are quieter, but have characteristic vibrations resulting from the electric drive.

5.2. Vibration measurements while driving

Vibration measurements inside the vehicle were taken in city and motorway traffic. The effective values of the acceleration of general vibrations were measured at speeds of 30 km/h and 50 km/h in city traffic and 100 km/h and 140 km/h in motorway traffic. The measurements were taken using a Siemens vibration measurement system with a seat measuring vibrations in three axes X, Y and Z, which was placed on the driver's seat. Each time, 10 measurements were taken, each lasting about 10 seconds. The temperature during the measurements was about 12°C, the weather was windless and without rain. The measurements were presented as an arithmetic mean of the collected results, rejecting the lowest and highest values. Examples of time histories of vibration amplitudes and frequencies prepared in MATLAB are shown in Fig. 7 and 8. The results are presented in the form of Fig. 9 to 12.

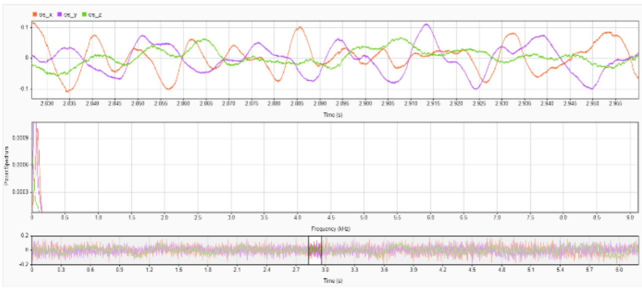

Fig. 7. Example of time course and frequency characteristics of vibration acceleration of an electric car

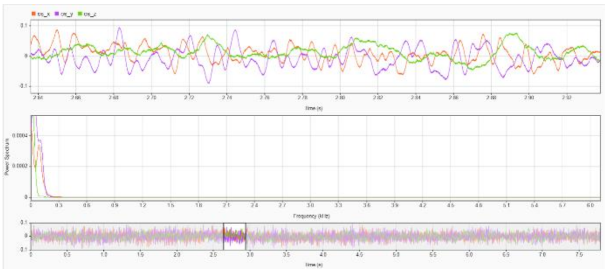

Fig. 8. Example of time course and frequency characteristics of vibration acceleration of a conventionally powered car

a) Vibration measurement in city traffic at a speed of 30 km/h

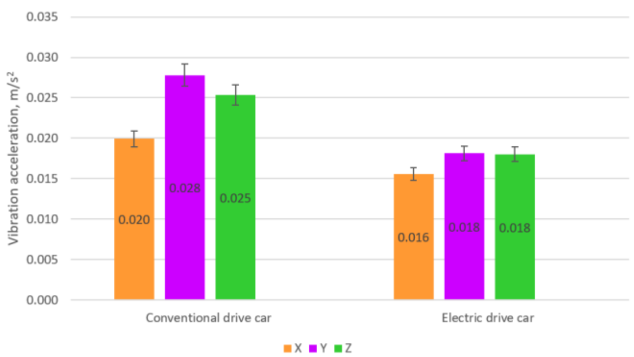

Fig. 9. Vibration acceleration in the X, Y, Z axes in vehicles at a speed of 30 km/h

During city driving at a speed of 30 km/h, electric cars were observed to generate lower levels of vibration in the Y-axis than conventionally powered cars. In the electric vehicle, the effective RMS (root mean square) values of the vibration acceleration in the Y-axis were 0.018 m/s², which means lower vibrations compared to the conventionally powered vehicle, which achieved 0.028 m/s². Higher vibrations in combustion cars may result from the operation of the drive system and additional sources of vibration typical of combustion engines.

b) Vibration measurement in city traffic at a speed of 50 km/h

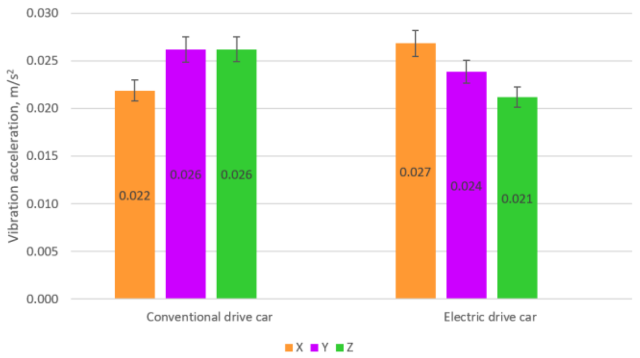

Fig. 10. Vibration acceleration in the X, Y, Z axes in vehicles at a speed of 50 km/h

At 50 km/h, vibration levels in conventional and electric cars were found to be very similar. In the conventional car, the effective vibration acceleration in the Y axis was 0.026 m/s², while in the electric car, it was 0.027 m/s² in the X axis. This means that at this speed, the differences in vibration levels between the drive types are minimal, suggesting that the effect of speed on the generated vibrations may be similar regardless of the drive type.

c) Vibration measurement in motorway traffic at a speed of 100 km/h

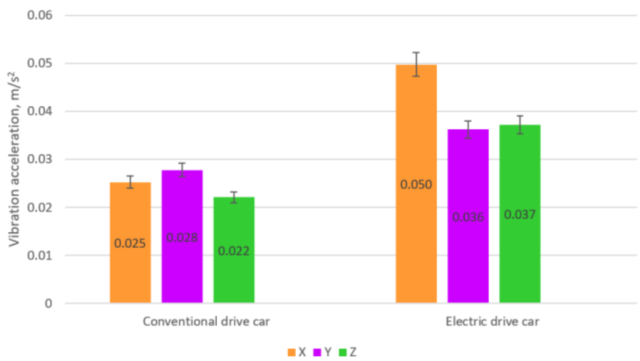

Fig. 11. Vibration acceleration in the X, Y, Z axes in vehicles at a speed of 100 km/h

While driving on the motorway at 100 km/h, an electric car experienced higher vibration levels than a vehicle with a combustion engine. In a vehicle with a conventional engine, the effective vibration acceleration was 0.028 m/s² in the Y axis, while in an electric car it was 0.05 m/s² in the X axis. Higher vibrations in an electric car may be due to several factors: poorer quality of workmanship, less sophisticated suspension and the lack of gear changes in the electric engine, which often operates at higher engine speeds. The lack of a gearbox in electric vehicles may cause increased vibrations transferred to the bodywork, because the engine operates more directly, without reducing vibrations during gear changes, which additionally affects driving comfort at high speeds.

d) Vibration measurement in motorway traffic at a speed of 140 km/h

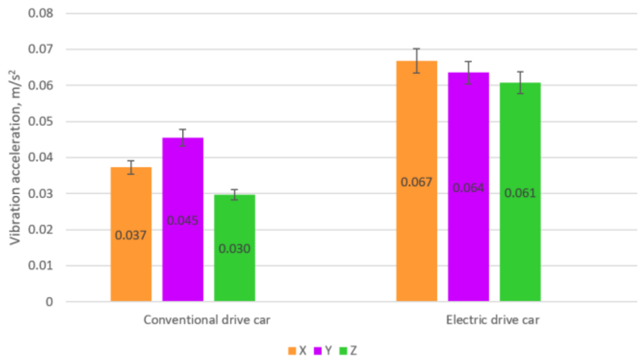

Fig. 12. Vibration acceleration in the X, Y, Z axes in vehicles at a speed of 140 km/h

When driving at a speed of 140 km/h, the highest vibration level was observed again in the electric car, where the effective vibration acceleration value was 0.097 m/s² in the X axis. In the vehicle with a conventional drive, the vibrations were lower, reaching 0.045 m/s² in the Y axis. The higher vibrations in the electric car may result from design limitations, such as simpler suspension, the lack of a gearbox, and a more direct transmission of driving forces without damping of gear changes. The lack of a mechanical gearbox means that the electric motor operates at a fixed gear ratio, which at high speeds can lead to increased vibrations transmitted to the body and reduced ride comfort.

The frequency range during driving in both vibration drives was from 10 Hz to 200 Hz in all axes for each drive type. Low and medium frequencies were related to road irregularities and vibrations, with vibrations caused by road irregularities and suspension system operation dominating.

The sampling frequency of 51,200 Hz was adopted at the measurement planning stage, before it was precisely determined which frequency bands would be most important in the analysis of vibrations in the vehicle. Initially, it was assumed that it would be worth using a high sampling frequency to avoid aliasing and to ensure the possibility of capturing also higher frequencies that could potentially appear in real driving conditions, e.g., as a result of resonances of suspension elements, engine, or drive system.

Only after conducting preliminary measurements and spectrum analysis did it turn out that the significant vibration band ends at around 200 Hz. Therefore, it can indeed be considered that the use of such a high sampling frequency was excessive in relation to the final needs of the analysis. However, from the perspective of data security and maintaining full measurement information, it was a prudent and justified decision.

It is also worth adding that modern data acquisition systems often operate by default with very high sampling rates, and limiting the signal bandwidth to the analyzed range (e.g., to 200 Hz) is done only at the data processing stage – e.g., by digital filtering. Therefore, a higher sampling rate does not necessarily mean increased noise, as long as the data is properly filtered and processed.

6. Conclusions

The results of the measurements of the effective values of vibration acceleration showed that the electric drive emits lower vibrations than the conventional drive during bench tests. In the vibration tests while driving for electric and conventional vehicles, the dominant frequencies were in the range from 10 Hz to 200 Hz, with lower and medium frequencies (10–100 Hz) present in all drives and resulting mainly from the unevenness of the road surface and the operation of the suspension system, while higher frequencies, particularly noticeable in vehicles with internal combustion engines, were related to the operation of the engine and its mechanical components. In the electric drive, the frequency range ended mainly at 100 Hz, because there were no additional vibrations generated by the internal combustion engine.

Measurements of vibrations affecting the driver and passengers while driving showed that the emission of vibrations increases with the increase in the speed of the vehicles. An increase in speed leads to an increase in the level of vibrations. The main source of vibrations while driving are vibrations resulting from the unevenness of the road surface and from the working suspension and shock absorption system of the vehicle and tires. The highest vibrations when driving at higher speeds were recorded for an electric car. An electric car shows very different vibration acceleration values depending on speed. At low speeds, vibrations are moderate, but at higher speeds (when driving on a motorway), vibration values increase significantly. This is due to the characteristics of electric motors, which, although they work smoothly, can generate vibrations resulting from higher revolutions at high speeds. The results suggest that in the case of a conventional vehicle, the vibration level depends on the driving speed, but the increase is not as pronounced as in an electric vehicle. In conventional cars, the use of a gearbox allows the torque to be adjusted to the driving conditions, which limits the increase in vibration at higher speeds. In electric vehicles, due to the direct drive and the lack of a gearbox, increasing the speed is associated with a proportional increase in the engine speed, which translates into higher vibration levels. This explains why the difference in vibration levels at different speeds is more noticeable in an electric vehicle than in a conventional one. Additionally, this vehicle had an uncomfortable suspension and a different mass distribution caused by the installed batteries, which also affects vibration emissions.

In practice, electric vehicle designers should pay special attention to ride comfort at higher speeds by appropriately tuning the suspension and vibration damping.

The results suggest that in the case of a conventional vehicle, the vibration level depends on the driving speed, but the increase is not as pronounced as in an electric vehicle. In conventional cars, the use of a gearbox allows the torque to be adjusted to the driving conditions, which limits the increase in vibration at higher speeds. In electric vehicles, due to the direct drive and the lack of a gearbox, increasing the speed is associated with a proportional increase in the engine speed, which translates into higher vibration levels. This explains why the difference in vibration levels at different speeds is more noticeable in an electric vehicle than in a conventional one.

The effective values of vibration acceleration considered comfortable, specified in the regulation [15], should not exceed 3.2 m/s^2 during short-term exposure and 0.8 m/s^2 during daily exposure. This means that the vibration acceleration values in all tested vehicles and on all drives affecting both the body and the driver and passengers meet the standard, do not pose a threat, and are considered comfortable.

The obtained vibration values are lower than the permissible limits specified in the standards, but this does not mean that the standards are excessive. The standards apply to a wide range of work environments, including those where the employee has direct contact with devices generating intense vibrations. An example would be a pneumatic hammer operator, where vibrations reach much higher levels than those occurring when driving a passenger car. In vehicles, however, driving comfort is an important factor, which is why the design of seats and suspension systems effectively dampens vibrations.

Nomenclature

a_{hvi}	vector sum of effective vibration accelerations
a_{hwxi}	effective weighted vibration acceleration values
a_{hwi}	value of the vector sum of effective weighted vibration accelerations
EV	electric cars
HEV	hybrid cars
RMS	root mean square

Bibliography

[1] Adamczyk J, Targosz J. Drgania drogowe (in Polish). Wydaw. KRIDM, AGH, Kraków 2003.

[2] Bhuiyan MHU, Fard M, Robinson SR. Effects of whole-body vibration on driver drowsiness: A review. J Safety Res. 2022;81:175-189. https://doi.org/10.1016/j.jsr.2022.02.009

[3] Bisu CF, Darnis P, Gerard A, K'nevez JY. Displacements analysis of self-excited vibrations in turning. Int J Adv Manuf Technol. 2009;44:1-16. https://doi.org/10.1007/s00170-008-1815-8

[4] Fiebig W. Drgania i hałas w inżynierii maszyn (in Polish). Wydawnictwo WNT. Warsaw 2020.
[5] Ghazali MHM, Rahiman W. Vibration analysis for machine monitoring and diagnosis: A systematic review. Shock Vib. 2021;2021(2):1-25. https://doi.org/10.1155/2021/9469318
[6] Greenblatt RE, Pflieger ME, Ossadtchi AE. Connectivity measures applied to human brain electrophysiological data. J Neurosci Methods. 2012;207(1):1-16. https://doi.org/10.1016/j.jneumeth.2012.02.025
[7] Horváth K, Zelei A. Simulating noise, vibration, and harshness advances in electric vehicle powertrains: strategies and challenges. World Electr Veh J. 2024;15(8):367. https://doi.org/10.3390/wevj15080367
[8] Kerber S, Fastl H. Prediction of perceptibility of vehicle exterior noise in background noise. Proc DAGA'08. Dresden 2008.
[9] Krishna K, Mahesha GT, Hegde S, Shenoy BS. A review on vibrations in electric and hybrid electric vehicles. J Inst Eng (India) Ser C. 2023;104(11):423-438. https://doi.org/10.1007/s40032-023-00930-3
[10] Mahdisoozani H, Mohsenizadeh M, Bahiraei M, Kasaeian A, Daneshvar A, Goodarzi M et al. Performance enhancement of internal combustion engines through vibration control: State of the art and challenges. Appl Sci. 2019;9(3): 406. https://doi.org/10.3390/app9030406
[11] Nader M. Drgania i hałas w transporcie (in Polish). Oficyna Wydawnicza Politechniki Warszawskiej. Warszawa 2016.
[12] Olabi AG, Abdelkareem MA, Wilberforce T, Alkhalidi A, Salameh T, Abo-Khalil AG et al. Battery electric vehicles: Progress, power electronic converters, strength (S), weakness (W), opportunity (O), and threats (T). Int J Thermofluids. 2022;16:100212. https://doi.org/10.1016/j.ijft.2022.100212
[13] Obsługa techniczna Dacia (in Polish). Dacia; 2024. https://www.dacia.pl/obsluga-techniczna.html (accessed on 6.04.2024).
[14] Qin Y, Tang X, Jia T, Duan Z, Zhang J, Li Y et al. Noise and vibration suppression in hybrid electric vehicles: state of the art and challenges. Renew Sustain Energy Rev. 2020; 124:109782. https://doi.org/10.1016/j.rser.2020.109782
[15] Reina G, Leanza A, Messina A. On the vibration analysis of off-road vehicles: influence of terrain deformation and irregularity. J Vib Control. 2018;24(22). https://doi.org/10.1177/1077546318754682
[16] Rozporządzenie Ministra Rodziny, Pracy i Polityki Społecznej z dnia 12 czerwca 2018 r. w sprawie najwyższych dopuszczalnych stężeń i natężeń czynników szkodliwych dla zdrowia w środowisku pracy, Dz.U. 2018 poz. 1286 (in Polish).
[17] Simcenter SCADAS XS: Wszystko co musisz wiedzieć (in Polish). ECTS 2024. https://www.ects.pl/artykul/simcenter-scadas-xs-wszystko-co-musisz-wiedziec/ (accessed on 10.09.2024).
[18] Tatsuno J, Maeda S. Effect of whole-body vibration exposure in vehicles on static standing balance after riding. Vibration. 2023;6(2):343-358. https://doi.org/10.3390/vibration6020021
[19] Verheijen ENG, Jabben J. Effect of electric cars on traffic noise and safety. National Institute for Public Health and the Environment 2010. Report 680300009/2010.
[20] Wang X, Osvalder A-L, Höstmad PBU. Influence of sound and vibration on perceived overall ride comfort – a comparison between an electric vehicle and a combustion engine vehicle. SAE Int J Veh Dyn Stab and NVH. 2023;7(2):1543-171. https://doi.org/10.4271/10-07-02-0010
[21] Wróblewski P, Drożdż W, Lewicki W, Miązek P. Methodology for assessing the impact of aperiodic phenomena on the energy balance of propulsion engines in vehicle electromobility systems for given areas. Energies. 2021;14(8): 2314. https://doi.org/10.3390/en14082314
[22] Yoshinaga H, Namikawa Y. Predicting noise reduction by electrification of automobiles. Inter-Noise 2009 Congress; Ottawa 2009.

Wioletta Cebulska, MEng. – Faculty of Transport and Aviation Engineering, Silesian University of Technology, Poland.
e-mail: *wioletta.cebulska@polsl.pl*

Damian Hadrys, DSc., DEng., Prof. PŚl. – Faculty of Transport and Aviation Engineering, Silesian University of Technology, Poland.
e-mail: *damian.hadrys@polsl.pl*