Article citation info:
Bieniek A, Graba M, Mamala J, Augustynowicz A, Szczepanek M. Analysis of passenger car powertrain system measurements in road conditions. Combustion Engines. 2023;195(4):144-151. https://doi.org/10.19206/CE-170207

Andrzej BIENIEK
Mariusz GRABA
Jarosław MAMALA
Andrzej AUGUSTYNOWICZ
Michał SZCZEPANEK

Combustion Engines
Polish Scientific Society of Combustion Engines

Analysis of passenger car powertrain system measurements in road conditions

ARTICLE INFO

Received: 2 June 2023
Revised: 31 July 2023
Accepted: 31 July 2023
Available online: 19 August 2023

The paper is focused on presenting a methodology for measuring power and torque based on diagnostic equipment available in most diagnostic workshops, such as OBD interfaces or the CAN Bus on-board data transmission network, under real-world road conditions. The publication presents an algorithm for calculating the powertrain's torque and power based on measurements of changes in vehicle speed or acceleration recording during a two-phase road test. The results presented, based on the method described, apply to both the internal combustion and electric vehicle. Common powertrain operating parameters, such as maximum power, maximum torque and the powertrain's flexibility parameters described in the literature, are proposed for the final evaluation of the vehicle's traction system.

Key words: *power and torque measurement, drive system, powertrain, road conditions, electric drive*

1. Introduction

Recently, there has been a definite increase in the market share of hybrid and electric drives [2]. However, regardless of the vehicle's powertrain, the issues of its diagnostics and verification of whether its current operating parameters correspond to the original designers' assumptions remain. The powertrain's operating parameters are linked to the vehicle's dynamic properties [11, 15] and often determine the choice of a particular vehicle. Modern powertrains generate higher torques than units produced a decade earlier, and the drive system's operation is controlled by sophisticated control systems. If their operation is disrupted, for example by faulty sensor readings, the disruption causes a reduction in the powertrain's torque and power, but often also results in an uncontrolled increase in environmental emissions [12, 16]. The powertrain's related malfunction is then recorded as a fault in the OBD network [13]. Once the fault has been removed, not only should a repeated diagnosis be carried out to verify the repairs under workshop conditions, but, more importantly, a test drive should be carried out in real-world road conditions by qualified workshop personnel.–In such conditions, it is possible to check the available sensors' readings using a diagnostic device to make sure they correspond to the set values. However, all diagnostic tests are carried out without any load on the powertrain, corresponding to real-world driving conditions. Only a check of the powertrain's parameters and operating parameters under load gives true information about its technical condition. The reason for this is the lack of appropriate workshop equipment, such as a chassis dynamometer. Such a dynamometer also requires the preparation of proper technical infrastructure and the employment of staff suitably trained to operate it. Hence, dynamometers are often reserved for workshops specialising in the optimisation and verification of the operating parameters of sports vehicle powertrains.

Nevertheless, most mechanical workshops verify the repairs by performing a test drive under real-world road conditions, during which an acceleration test is carried out to subjectively assess the correct functioning of the drive system and other components. The acceleration test is a process of vehicle acceleration from a standstill to a preset target speed using specific transmission gear ratios. It is also possible to carry out a so-called flexibility test [19]. The flexibility test can be perceived as the process of vehicle acceleration while driving in one selected gear. In both cases, the proper implementation of such a defined acceleration process most often requires the powertrain's power supply control equipment to be set to full power. In the case of manual transmission and acceleration through gears, the ratio must be changed at a strictly defined speed that characterises the powertrain's operation. In this case, the outcome of the acceleration process is assessed subjectively and depends on the experience of the workshop personnel performing the test. Its assessment is mainly based on the feeling of the vehicle's acceleration dynamics, i.e. the increase in speed over time. The assessment is less frequently done by measuring the acceleration time to reach the target speed or the time needed to travel a certain distance [4]. Time is a measurable index, but it does not directly determine the drive system's operating parameters and has no direct reference to its external characteristics. A fundamental question can then be formulated: Is it possible to assess the correctness of a powertrain's repairs under road test conditions with the common diagnostic equipment used in workshops? At the same time, can the powertrain's basic operating parameters in the form of power, torque and flexibility be determined? In this respect, the authors of this elaboration carried out comparative measurements of the operating parameters in a passenger vehicle's internal combustion and electric drive system during a road test using a workshop diagnostic device.

2. Operating parameters and the powertrain's flexibility

Carrying out the acceleration test at full intensity in a road test, especially within a single gear, is an example of loading a vehicle's drive system, not only by the basic forces of rolling drag and aerodynamic drag, but also by the load associated with mass inertia in progressive motion and the inertia of rotating components [17]. The inertia force counteracts the vehicle's acceleration process and its value is directly proportional to the product of the vehicle's mass and the resulting acceleration. The vehicle's mass is constant and the greater the acceleration, the higher the inertia force. The inertia force is the apparent force that maintains the power balance in the drive system (1).

$$\mathrm{N_n = N_{op}} \tag{1}$$

where:

$$\mathrm{N_n = F_n \cdot v} \tag{2}$$

$$\mathrm{N_{op} = (F_t + F_p + F_i) \cdot v} \tag{3}$$

where: $\mathrm{N_n}$ – traction power, kW; $\mathrm{N_{op}}$– motion drag, kW; $\mathrm{F_n}$ – driving force, kN; v – vehicle speed, m/s; $\mathrm{F_t}$ – rolling drag, kN; $\mathrm{F_p}$ – air resistance, kN; $\mathrm{F_i}$ – inertia force, kN.

Such a test involves using all available power in the drive system to accelerate the vehicle at maximum intensity. In such a test, the vehicle mass is accelerated in a progressive motion and rotating masses are accelerated, while the increase in the vehicle's speed is a measure of the power applied to the vehicle's driven wheels. Full acceleration intensity allows the powertrain to operate on an external speed characteristic curve which can be used to determine interesting powertrain operating parameters, such as power and torque as a function of drive shaft speed. Detailed analysis allows for assessing the vehicle's traction properties and determining the drive system's flexibility field. The powertrain's flexibility is the ability to change its load as represented by the torque waveform between the values of the drive shaft speed at maximum torque ($\mathrm{n_{Mmax}}$) and maximum power ($\mathrm{n_{Nmax}}$). This property is expressed by the torque and speed flexibility index and is widely described in the literature [14, 17] as the powertrain's shaft speed flexibility:

$$\mathrm{e_n = \frac{n_{N_{max}}}{n_{M_{max}}}} \tag{4}$$

and torque flexibility

$$\mathrm{e_M = \frac{M_{max}}{M_{Nmax}}} \tag{5}$$

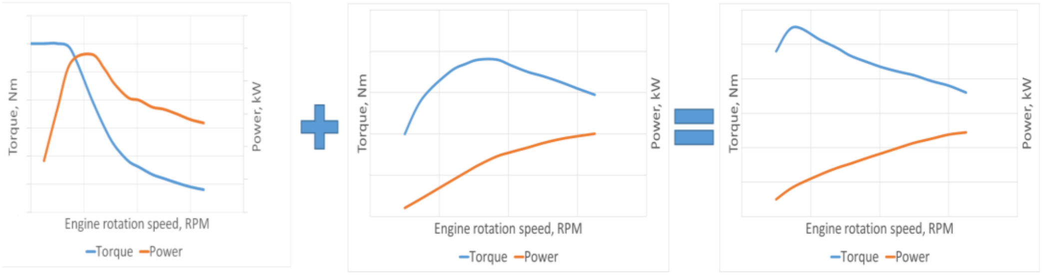
where: $\mathrm{n_{N_{max}}}$ – speed at maximum power, rpm; $\mathrm{n_{M_{max}}}$ – speed at maximum torque, rpm; $\mathrm{M_{max}}$ – maximum torque, Nm; $\mathrm{M_{Nmax}}$ – torque at the powertrain's maximum power, Nm.

On other hand, total flexibility was written down as:

$$\mathrm{e_c = e_n \cdot e_M} \tag{6}$$

The flexibility coefficients of many modern powertrains depend on the external torque and power curves in the speed characteristics and the possible interoperation between the powertrains used (Fig. 1).

The rapid development of powertrains, and in particular their hybridisation, is changing their flexibility and even enabling vehicle manufacturers to shape it through appropriate control of the individual power units interoperating in a given drive system. The combination of an internal combustion engine and an electric engine that interoperate in a single drive system is also an answer to the challenge faced by the automotive industry in the modern world. On the one hand, it reduces emissions of pollutants into the environment and, on the other hand, allows the power in the drive system to be shaped accordingly. Determining the powertrain's flexibility and, therefore, the power's and torque's flexibility in the drive system by means of a road test is possible for any configured passenger vehicle drive system. The determination of these parameters requires carrying out a test involving vehicle acceleration from a pre-set initial speed to the target speed with a fixed drive system transmission ratio. Hence, such a test can be performed under real-world road conditions during a test drive. However, the element essential to ensure the test's correctness is to read the data at a frequency that allows the dynamics of the vehicle's speed changes to be identified. The time required to reach the target speed (not necessarily the maximum speed) enables the tested powertrain's operation to be assessed. It is therefore, possible to monitor in detail the acceleration's waveform and its instantaneous declines in value. The results of speed changes recorded only during the acceleration process are insufficient to determine the powertrain's operating parameters due to the losses occurring in the drive system. This depends on the transmission's type, the mass inertia in the drive system, the losses from the vehicle's turning wheels and the impact of atmospheric conditions on the vehicle. The test is therefore complemented with an idle run from the end speed to the flexibility test's starting speed.



Characteristic of a electric motor

Characteristic of a gasoline engine

Characteristic of a hybride power unit

Fig. 1. External characteristics of various powertrains in passenger cars

As demonstrated by the authors of [6, 10], a two-phase road test allows for the compensation of the vehicle's motion drag, mass inertia (and masses in rotary motion) in the powertrain and the impact of environmental conditions on the powertrain's determined operating parameters and flexibility. At the same time, it is recommended that the flexibility test in the road test be carried out on a road section with a constant slope. Measurement sections based on a flat horizontal road surface enable obtaining repeatable and reliable results.

3. Measurements of operating parameters in the road test

A number of measuring devices are used in the measurement methods intended for determining the powertrain's operating parameters and flexibility in the proposed two-phase acceleration and idle run test. These devices allow changes in the vehicle's speed, and consequently changes in its acceleration to be measured by direct and indirect methods. The direct methods include measuring the vehicle's longitudinal acceleration using an accelerometer attached directly to its body. In this context, it is not only the recording of the changes in acceleration over time that is important, but also the accelerometer's mounting position and method, the sampling frequency, the road surface's condition, the centre of gravity or the vehicle's suspension system. The effects of the above-mentioned factors on the recorded acceleration require the development of a suitable calculation algorithm related to the change in the measuring axes' orientation relative to the road in the X-Z plane due to the change in the vehicle suspension's deflection during acceleration and idle run.

The application of indirect methods to measure acceleration requires using specialised measuring equipment. Very good results for measuring the vehicle's speed and then calculating the acceleration can be obtained by using the Peiseler 5th wheel, Correvit optical head, radar or GPS devices, by measuring the vehicle's wheel speed or using information from the OBD network [3, 18]. All these methods show varying accuracy in terms of speed measurement, which often depends on the device's sophistication and price.

4. Research methodology

4.1. Test objects

The flexibility test was carried out with the use of two test vehicles, i.e. passenger vehicles, the basic technical data of which are presented in Table 1. The Audi vehicle was equipped with an internal combustion engine (ICE), while the Renault Zoe was powered by an electric engine (full BEV – Battery Electric Vehicle).

The flexibility test in the road test was carried out on a closed road section of 4 km, with a constant road slope close to zero and a good road surface. The ambient temperature was 15–19^{o}C, atmospheric pressure amounted to 1014 hPa, while wind speed was 1.67 m/s, and its direction was perpendicular to the test road.

Table 1. Basic parameters of test objects

	Parameter	Unit	AUDI A4 B6	Renault ZOE
1.	Maximum power	kW	96	68
2.	Speed at max power	rpm	4000	8000
3.	Maximum torque	Nm	310	210
4.	Speed at max torque	rpm	1900	0
5.	Vehicle mass during test	kg	1705	1725
6.	Wheel size	–	235/40 R18	195/55 R16
7.	Main transmission ratio	–	3.444	-
8.	3/4 gear ratio	–	1.360/ 0.903	-
9.	Total gear ratio	–	4.683/ 3.110	9.300
10.	Torque flexibility	–	1.240	2.58
11.	Crankshaft speed flexibility	–	2.110	∞
12.	Total flexibility	–	2.616	∞

4.2. Measurement equipment

The study utilised a two-phase test to determine the operating parameters of two different passenger vehicle drive systems using workshop diagnostic equipment. A diagnostic device intended for reading data from the OBD network and an interface for reading parameters from the CAN BUS on-board data transmission network were used in the tests. The proposed two-phase test was used for both measuring devices and was carried out at a constant drive system ratio.

The research was carried out during road tests, involving recording the powertrain's operating parameters with a diagnostic device which enabled saving the data in a data file. Once connected to the on-board diagnostic network via the OBD socket and logged into the measured value block, selected parameters of the tested powertrain, such as time, engine crankshaft speed and vehicle speed during the test, can be recorded. A complication of this measurement method is the need to develop a measurement algorithm to determine the powertrain's operating parameters from the obtained measurement data [8], obtained, for example, with the use of the inertia method [1, 9] or the load method [5, 7]. An interface for reading the parameters from the CAN BUS on-board data transmission network can also be used to measure the powertrain's operating parameters. The interface also allows for recording many other parameters.

4.3. Two-phase test method for determining the powertrain's operating parameters

The two-phase road test method is based on carrying a run-in and idle run during a single measurement (Fig. 2). An important rule is to carry out the acceleration at full intensity with a constant ratio in the transmission that does prevents the driving force limit to be exceeded (prevents wheel slip) under the prevailing road conditions, taking into account the driven wheels' traction. Irrespective of the measuring device used, exceeding the driving force limit has an adverse effect on the accuracy of the measurement of the powertrain's operating parameters or even makes this measurement impossible.

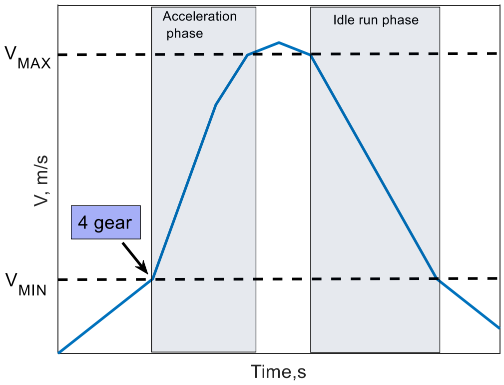


Fig. 2. Speed profile in the flexibility test

During acceleration, it is necessary to measure such parameters as time, vehicle speed or acceleration. These parameters are needed to determine the basic operating parameters, such as the power expended to change the vehicle’s kinetic energy at the given acceleration (1). Since the vehicle's kinetic energy is obtained during the acceleration measurement in the first acceleration phase, it is reduced in the subsequent idle run phase by the energy associated with the basic motion drag, and the mass inertia drag in progressive and rotational motion. The second phase should be carried out under the same road and ambient conditions, preferably immediately after the acceleration phase (Fig. 2).

$$\Delta E_{k(V)} = \\ = \frac{m({v_{R(n)}}^2 - {v_{R(n-1)}}^2)}{2} + \frac{m({v_{w(n-1)}}^2 - {v_{w(n)}}^2)}{2} \tag{7}$$

where: $\Delta E_{k(V)}$ – kinematic energy change in the speed range, m – vehicle mass, V_R – vehicle linear speed during acceleration, V_W – vehicle linear speed during idle run, n – matrix index.

The final results of the powertrain’s operating parameters are obtained in the proposed calculation algorithm (Fig. 3).

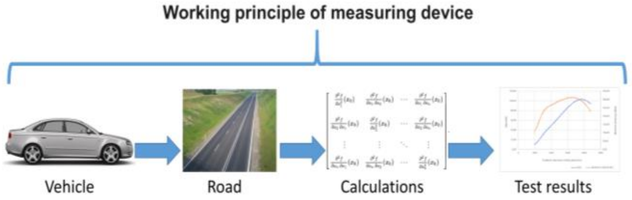


Fig. 3. Calculation algorithm for determining the powertrain’s operating parameters and flexibility

The calculations of the powertrain’s operating parameters and flexibility rely heavily on the measurement of the vehicle’s kinematic parameters and the continuous measurement of its linear speed v, time, as well as other drive system operating parameters, such as accelerator pedal opening angle, shaft speed, intake air pressure, airflow pressure or fuel pressure. Recording of these parameters can be performed from the vehicle's OBD network [13] or from the on-board data transmission network. Due to the data transmission rate, it is a good idea to limit the amount of data recorded to the minimum necessary for the OBD system. The instantaneous values of the flexibility test’s measurement parameters are simultaneously recorded as matrix elements labelled for the acceleration phase with the subscript R, and for the idle run phase with the subscript W (Fig. 4).

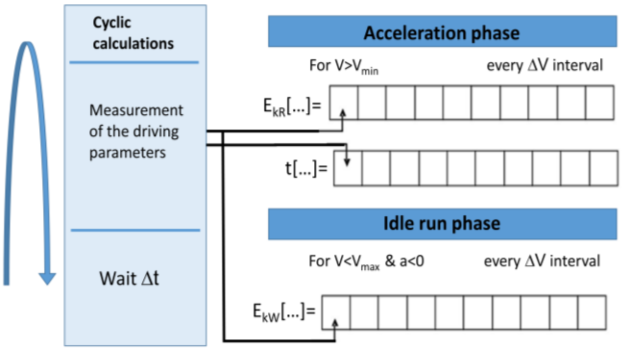


Fig. 4. Algorithm for matrix data storage during the two-phase test

At the same time, the recording’s increment determinant for both matrices is the change in the vehicle's linear speed v (Fig. 5). It should be noted that the kinetic energy state and other recorded operating parameters at which the instantaneous kinetic energy states E_{kR} and E_{kW} were determined are stored in the matrix for velocity v under the same index.

Finally, at the end of the test, the change in the vehicle’s kinetic energy is obtained with a corresponding change in vehicle speed. This allows for recording the dependency enabling the determination of the powertrain’s operating parameters and flexibility in the given time interval. Equation (8) allows to determine the power.

$$N = \frac{|\Delta E_{kR}|}{|\Delta t_R|} + \frac{|\Delta E_{kW}|}{|\Delta t_W|} \tag{8}$$

where: $\Delta E_{kR/W}$ – change in energy for the given linear speed range, $\Delta t_{R/W}$ – change in time for the given linear speed range.

The power determined by the two-phase method takes into account changes in the vehicle’s kinematics separately for the acceleration and idle run phases. The main advantage of this method is that carrying out a test of the correct operation of the drive system does not require the possession of specialized test stands, but only the available diagnostic equipment. Additionally, the proposed method takes into account the basic resistances occurring during the movement of the vehicle, which should give results much closer to the real ones in comparison to the simplified methods on which some diagnostic testers are based. However, the interpretation of the results obtained during the road test requires a deeper analysis. and comparisons to the drive system performance indicators provided by the manufacturer. Further mathematical operations, according to equation (9), enable the determination of the torque:

$$M = \frac{N}{2 \cdot \pi \cdot n} \tag{9}$$

The maximum power and torque values incremented for the nth matrix element in the form of the powertrain’s shaft speed allow for the determination of the powertrain's flexibility and its external speed characteristics curve waveform.

5. Analysis of results – the powertrain's operating parameters and flexibility

5.1. Internal combustion powertrain

As standard, the powertrain or other vehicle components diagnostics can be carried out via the diagnostic interface using the OBD diagnostic connector with the VCDS diagnoscope. At the same time, it is possible to save the values measured in the on-board diagnostic network in a file while driving on the road. In this case, the data so recorded for the test car was used in the flexibility test, and the test run was carried out for gears 3 and 4. Figure 5 shows the test for gear 3.

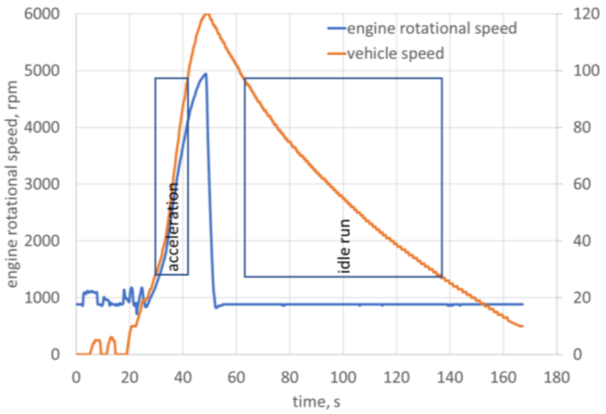


Fig. 5. Flexibility test demonstrating the speed change over time for the VCDS at gear 3

Once the calculations have been made according to the algorithm shown in Fig. 4, the waveform of the powertrain's operating parameters for full acceleration intensity can be determined. It is important to linearize and condense the measurement points in the flexibility test analysis process for both the acceleration and idle run phases, as the VCDS interface records the data at a frequency of approx. 3 ±1 Hz. Figures 6 and 7 show the waveform of the powertrain's operating parameters for gears 3 and 4.

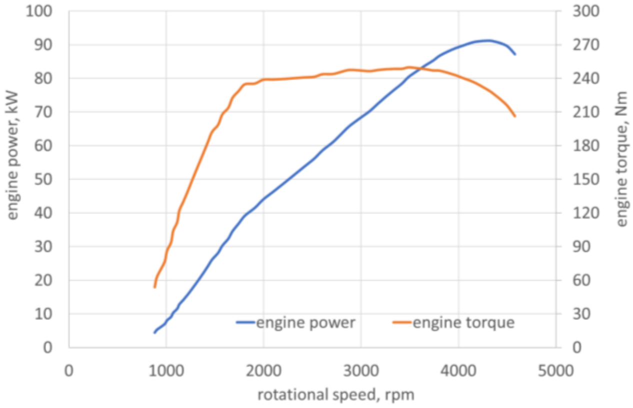


Fig. 6. Speed characteristics of power and torque in the flexibility test for gear 3

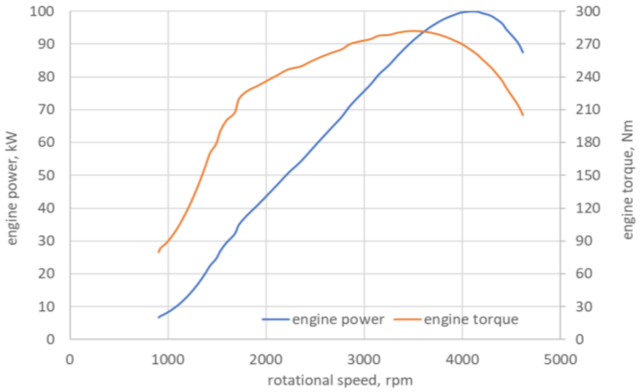


Fig. 7. Speed characteristics of power and torque in the flexibility test for gear 4

The flexibility test was repeated multiple times and the average values are presented in Table 2.

Table 2. Maximum parameters obtained using the VCDS interface for the Audi A4

Measured gear	N_{max}, kW	n, rpm	M_{max}, Nm	n, rpm	M_{Nmax}, Nm
3	91.16	4326	249.72	3486	228.22
4	99.94	4074	281.67	3591	265.66

An analysis of the discrepancies between the data reported by the manufacturer (Fig. 8) and that obtained in the road test using the VCDS diagnostic interface is shown in Tables 3 and 4.

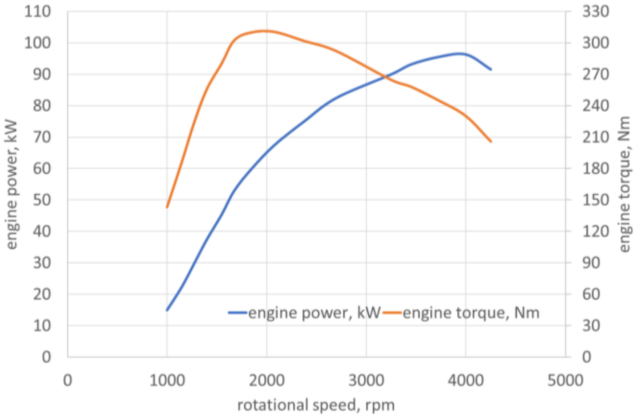


Fig. 8. Manufacturer speed characteristics of power and torque

Table 3. Absolute differences in the parameters compared to the nominal (factory) values for the Audi A4

Measured gear	ΔN_{max}, kW	Δn, rpm	ΔM_{max}, Nm	Δn, rpm	ΔM_{Nmax}, Nm
3	–4.84	326	–60,28	1586	–21.78
4	3.94	74	–28.33	1691	15.66

Table 4. Relative differences in the parameters compared to the nominal (factory) values for the Audi A4

Measured gear	ΔN_{max}, %	Δn, %	ΔM_{omax}, %	Δn, %	ΔM_{Nmax}, %
3	–5.04	8.15	–19.45	83.47	–8.71
4	7.34	1.85	–9.14	89.00	6.26

An analysis of these differences shows the occurrence of significant differences, mainly for rotational speeds, whose values are higher than 80% and for engine torque the differences are between 9.14 to 19.45% to nominal values (Table 4). This affects subsequent parameters, such as flexibility. The maximum values of power show a slight deviation of a few percent from the nominal values provided by the manufacturer, and their nature (both positive and negative deviations) may suggest, on one hand, that the road method isn't perfect by pointing to its measurement accuracy related to the frequency of recording the operating parameters from the OBDII diagnostic network, lower accuracy of used sensors and, on the other hand, that real-world values are very close to the nominal values. In addition, it should be noted that many manufacturers allow slight deviations of several percent of individual parameters, such as power, torque or rotational speeds values at which individual operating indicators are achieved in cars of the same series and model, which is confirmed by tests carried out on certified research test stands.

During the measurement carried out at the set ratio, high repeatability of the results was achieved. The relative difference in power measurement for each test did not exceed 1% of the average value obtained in all tests. Therefore, the calculations for each of the tests provided almost identical results. However, the results for individual gears shown differences in both engine power and torque. These values vary considerably: the maximum values for power at gear 3 are 5.04% lower and at gear four the values are 7.34% higher than the nominal values provided by the manufacturer. The different waveforms of the powertrain's operating parameters also resulted in a change in total flexibility, which was 48.1% lower for gear 3 and 54.0% lower for gear four than the values derived from the factory data. The discrepancies obtained are mainly due to differences between the respective reference speeds (as stated by the manufacturer) and those actually obtained due to the dynamics of the acceleration process. The individual flexibility parameters are summarised in Table 5.

Table 5. Flexibility parameters obtained using the VCDS interface for the Audi A4

Measured gear	e_M	e_n	e_c	Difference in e_c, %
gear 3	1.094	1.241	1.358	–48.1
gear 4	1.060	1.134	1.203	–54.0

These differences are the result of the selected gear during the flexibility test, which was carried out at the same, i.e. maximum, intensity in both cases.

5.2. Electric powertrain

The two-phase test was used to determine the powertrain's operating parameters and flexibility for another vehicle, i.e. the Renault ZOE. The flexibility tests were carried out for the drive system's Eco and Normal control modes. The Eco mode limits the available power in the drive system while limiting the temperature inside the car to 21°C. The Normal mode is characterised by the drive system's full power availability.

During the measurement carried out on the electric vehicle, high repeatability of the results was achieved and the relative error in power measurement for each test did not exceed 1% of the average value obtained in all tests (Table 6). These measurements were made with CAN BUS on-board data transmission network via the SYS TEC interface, where the highest recording frequency was close to 100 Hz.

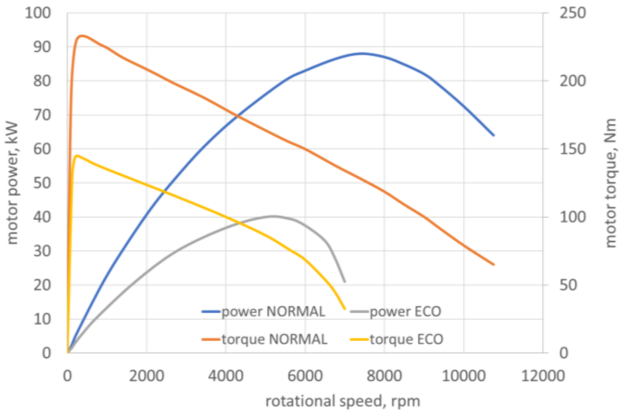


Fig. 9 Speed characteristics of power and torque in the flexibility test for the electric vehicle's Eco and Normal modes

Table 6. Maximum parameters obtained for the Renault Zoe

Designation	N_{max}, kW	n, rpm	M_{max}, Nm	n, rpm	M_{Nmax}, Nm
Eco	40.00	4950	144.52	150	77.20
Normal	88.00	7650	231.66	225	126.72

Table 7. Absolute differences in the parameters compared to the nominal values for the Renault ZOE

Designation	ΔN_{max}, kW	Δn, rpm	ΔM_{max}, Nm	Δn, rpm
Eco	0.00	–50	0.2	150
Normal	20.00	–350	21.66	225

Table 8. Relative differences in the parameters compared to the nominal values for the Renault ZOE

Designation	ΔN_{max}, %	Δn, %	ΔM_{max}, %
Eco	0	–1.00	0.26
Normal	29.41	–4.45	10.31

A summary of the flexibility parameters for the electric vehicle is presented in Table 9.

Table 9. Flexibility parameters for the Renault Zoe

Designation	e_M	e_n	e_c
Eco	1.872	34.000	63.648
Normal	1.828	34.000	62.152

As demonstrated in Table 6, the maximum torque and power values in the electric drive system vary considerably depending on the drive mode used. In the Eco mode, the maximum drive power has been limited to 40 kW, which is about 45% of the nominal power. A reduction of the maximum torque to 62% of the nominal value was also noted. At the same time, it should be noted that the electric powertrain can be briefly loaded above its nominal value without adversely affecting its durability. The Normal mode allowed for obtaining almost 30% more power compared to the nominal value during acceleration at maximum intensity and the higher power was available in the first acceleration phase. Also, the maximum torque was more than 10% higher than its nominal value. The tested drive system does not have a gearbox, so both Eco and Normal modes measurements were carried out at the same overall gear ratio. The flexibility parameters for the two drive modes are very similar and the difference between the total flexibility index is approximately 2%. A comparison of the total flexibility parameters e_c shows that the electric passenger vehicle has higher (up to about 40 times) flexibility than the internal combustion vehicle.

6. Summary

The subject matter presented in the paper concerned the determination of power and torque and was aimed to verify their maximum values in a road test. The results obtained are largely consistent with the technical parameters specified in the factory data of the passenger vehicles tested. The small discrepancies of a few per cent for the internal combustion engine, being both positive and negative in nature, may indicate that the tested powertrain's real-world maximum operating parameters are very close to the nominal values stated by the manufacturer. Such values may suggest a good overall technical condition of the entire drive system, in particular the absence of significant mechanical faults. The determined power maximal values show that they are close to factory data without value fluctuations or significant differences. However, a significant shift in the maximum value was noticed, especially in terms of engine torque, towards much higher rotational speeds and lower maximal value (up to 20%) in relation to the data provided by the manufacturer. When analyzing the total elasticity index in this case, there are clear differences between the factory data and those obtained during the test, amounting to about 50% of the discrepancy between the factory and test values. This may indicate improper control, e.g. of the amount of air flowing to the engine related to the operation of the supercharging system. In the case of the electric drive system, the possibility of temporarily overloading the powertrain beyond the nominal values of power (by about 30%) and torque (by about 10%) also points to its good technical condition. Repeated measurements show significant repeatability under the same road conditions and on the same device. At the same time, the high frequency of the recorded data allows for determining very even and smooth power and torque characteristics. This allows for the conclusion that the proposed methodology, which utilises workshop diagnostic equipment and a two-phase road test, has satisfactory accuracy for obtaining basic torque and power parameters for different types of powertrains. The waveforms obtained can be used to assess the technical condition and in extended diagnostics of the vehicle's drive system. At the same time, the flexibility parameters determined on their basis deviate from the original data due to the reading of specific maximum values from the characteristics, which are influenced by many factors such as recording speed or process dynamics.

Acknowledgements

The paper is co-funded by the "DELTA" programme of the Opole University of Technology for researchers in 2021.

Nomenclature

BEV	battery electric vehicle
CAN	controller area network
ICE	internal combustion engine
OBD	on-board diagnostics
VCDS	VAG-COM diagnostic system

Bibliography

[1] Bździuch D. Measurement of engine operating parameters and diagnostic tests of motor vehicles on the VT-2 chassis dynamometer (in Polish). Autobusy: technika, eksploatacja, systemy transportowe. 2007; 6:560-568. bwmeta1.element.baztech-e4923386-3ba6-4208-9932-e5faf2878296

[2] Energy Agency I. Global EV Outlook 2022 Securing supplies for an electric future. 2022.

[3] Gardulski J. The fifth wheel as a part of a data acquisition system for diagnostic testing of car shock absorbers with vibroacoustic methods. Biuletin WAT 2011:1:83-91. bwmeta1.element.baztech-article-BWAW-0006-0041

[4] Graba M, Mamala J, Bieniek A, Sroka Z. Impact of the acceleration intensity of a passenger car in a road test on energy consumption. Energy. 2021;226: 120429. https://doi.org/10.1016/j.energy.2021.120429

[5] Haller P, Wróbel R, Dimitrov R, Michaylow V. Introducing new engine performance lab at the Department of Motor Vehicles and Combustion Engines of Wroclaw University of Technology. Combustion Engines. 2013;154(3):549-555.

[6] Hayes JG, Davis K. Simplified electric vehicle powertrain model for range and energy consumption based on EPA coast-down parameters and test validation by Argonne National Lab data on the Nissan Leaf. 2014 IEEE Transportation Electrification Conference and Expo. 2014:1-6. https://doi.org/10.1109/ITEC.2014.6861831

[7] Kolator B, Janulin M. Methodology for measuring car traction parameters. MATEC Web Conf. 2018; 182:02001. https://doi.org/10.1051/matecconf/201818202001

[8] Kubiak P, Krzemieniewski A, Lisiecki K, Senko J, Szosland A. Precise method of vehicle velocity determination basing on measurements of car body deformation–non-linear method for 'Full Size' vehicle class. Int J Crashworthiness. 2018;23(3):302-310. https://doi.org/10.1080/13588265.2017.1331692

[9] Kuranc A. Vehicle engine power tests using inertial methods (in Polish). Autobusy: technika, eksploatacja, systemy transportowe. 2012:13(10):119-124. bwmeta1.element.baztech-fd47b0d8-256a-48d9-8c7f-72f3c51f7f11

[10] Ligterink NE, van Mensch P, Cuelenaere RFA, Hausberger S, Leitner D, Silberholz G. Correction algorithms for WLTP chassis dynamometer and coast-down testing. 2014. https://climate.ec.europa.eu/system/files/2016-11/wltp_correction_algorithms_en.pdf

[11] Mamala J, Graba M, Bieniek A, Prażnowski K, Hennek K, Kołodziej S et al. Evaluation of energy consumption in the acceleration process of a passenger car. Combustion Engines. 2022;190(3):35-44. https://doi.org/10.19206/CE-142553

[12] Merkisz J, Rymaniak Ł. The assessment of vehicle exhaust emissions referred to CO_2 based on the investigations of city buses under actual conditions of operation. Eksploat Niezawodn. 2017;19(4):522-529. https://doi.org/10.17531/ein.2017.4.5

[13] Merkisz J, Mazurek S. On board systems for passenger vehicles (in Polish). WKiŁ. Warsaw 2002.

[14] Mysłowski J. The flexibility of modern spark ignition engines (in Polish). Autobusy: technika, eksploatacja, systemy transportowe. 2011;12(5):307-311. bwmeta1.element.baztech-article-BWAN-0021-0046

[15] Pielecha I, Pielecha J. Simulation analysis of electric vehicle energy consumption in driving test. Eksploat Niezawodn. 2020;22(1):130-137. https://doi.org/10.17531/ein.2020.1.15

[16] Pielecha J, Skobiej K, Kurtyka K. Exhaust emissions and energy consumption analysis of conventional, hybrid and electric vehicles in real driving cycles. Energies. 2020;13(23):6423. https://doi.org/10.3390/en13236423

[17] Prochowski L. Movements Mechanics (in Polish). WKiŁ. Warsaw 2016.

[18] Sapundzhiev M, Evtimov I, Ivanov R. Determination of the needed power of an electric motor on the basis of acceleration time of the electric car. IOP Conf Ser Mater Sci Eng. 2017;252:0120636. https://doi.org/10.1088/1757-899X/252/1/012063

[19] Szpica D. Coefficient of engine flexibility as a basis for the assessment of vehicle tractive performance. Chin J Mech Eng. 2019;32(1):1-9. https://doi.org/10.1186/s10033-019-0352-8

Andrzej Bieniek, DEng. – Faculty of Mechanical Engineering, Opole University of Technology, Poland.

e-mail: *a.bieniek@po.edu.pl*

Prof. Jarosław Mamala, DSc., DEng. – Faculty of Mechanical Engineering, Opole University of Technology, Poland.

e-mail: *j.mamala@po.opole.pl*

Mariusz Graba, DEng. – Faculty of Mechanical Engineering, Opole University of Technology, Poland.

e-mail: *m.graba@po.opole.pl*

Prof. Andrzej Augustynowicz, DSc., DEng. – Faculty of Mechanical Engineering, Opole University of Technology, Poland.

e-mail: *a.augustynowicz@po.opole.pl*

Michał Szczepanek, Eng. – Student in the Faculty of Mechanical Engineering, Opole University of Technology, Poland.

e-mail: *michal.szczepanek@student.po.edu.pl*