Article citation info:
Graba M, Hennek K, Mamala J, Prażnowski K, Mueller M. Acceleration dynamics of a passenger vehicle with an electric powertrain and their impact on the mileage energy consumption. Combustion Engines. 0000;XXX(X):xx-xx. https://doi.org/10.19206/CE-206090

Mariusz GRABA
Krystian HENNEK
Jarosław MAMALA
Krzysztof PRAŻNOWSKI
Maximilian MUELLER

Combustion Engines
Polish Scientific Society of Combustion Engines

Acceleration dynamics of a passenger vehicle with an electric powertrain and their impact on the mileage energy consumption

ARTICLE INFO

Received: 8 April 2025
Revised: 30 May 2025
Accepted: 9 June 2025
Available online: 22 July 2025

The aim of the paper was to analyse the effect of an electric vehicle's acceleration intensity on energy consumption in a real road test. The research involved the urban Skoda Citigo-e iV equipped with a proprietary measurement system. Acceleration tests were carried out at different accelerator pedal positions, analysing kinematic and energy parameters, including energy consumption, speed, acceleration, and power. The paper introduces a dynamics index, combining powertrain capacity with specific energy consumption, allowing an objective comparison of vehicle energy and traction efficiencies. The results indicate that moderate acceleration up to about 40% pedal position is the most energy efficient. Further increases in power result in a significant increase in energy consumption with little dynamic acceleration. The electric vehicle's acceleration dynamics were compared to those of an internal combustion vehicle, which showed similarity in terms of the moderate acceleration area. The results show that moderate acceleration is the most energy-efficient, and the presented acceleration dynamics index allows for an objective comparison of the efficiency of different powertrains.

Key words: *acceleration dynamics, energy consumption, electric vehicle, dynamic index, powertrain efficiency*

1. Introduction

Vehicles are an integral part of everyday life for many of us; Poland featured 723 cars per 1000 inhabitants at the end of 2024, according to Statistics Poland. This score is the highest among European Union members, as many car users use their cars for daily commuting or leisure. However, a passenger car has two main tasks. The first is to be designed to have good traction, and the second is to ensure the road user safety. The first task is simple in that, for technical reasons, a person can design any powertrain, but in light of the requirements to reduce carbon emissions and the carbon footprint, this is forcing a lot of improvements, modifications, and optimisation of the power units on car manufacturers. This applies equally to internal combustion (ICEV), hybrid (HEV), and electric (BEV) passenger vehicle, which produces zero emissions in the TTW system. On the other hand, ensuring the powertrain's good technical performance associated with achieving accelerations of the order of 5 m/s^2 or the ability to develop high travel speeds requires the powertrain to have a large power reserve [8, 11]. Power is needed not only to drive the vehicle's wheels, but also to power the vehicle's increasingly sophisticated and extensive range of accessories, securing not only travel comfort, but also road user safety by ensuring adequate controllability related to the acceleration required for manoeuvres such as merging into traffic or overtaking [1, 6, 10].

Therefore, the authors used this paper to analyse the acceleration intensity of an electric vehicle on the energy consumption in a road test. The passenger vehicle acceleration was carried out in a flexibility test from an assumed initial speed, for various constant accelerator pedal positions providing constant power in the powertrain, until reaching a speed at which acceleration reached values close to 0 m/s^2 or relatively 120 km/h. The analysis covered basic indices characterising the vehicle's movement, such as the speed profile's kinematic parameters or energy parameters in the form of energy consumption. In the energy balance of a vehicle in motion, the measure of the consumed electrical energy supplied from the traction batteries to the vehicle's powertrain and auxiliary equipment is the realised speed profile describing its movement dynamics [3].

2. Acceleration as a fundamental phase of vehicle motion

The maintenance of good traction performance during acceleration is one of the most important phases of movement in terms of energy consumption, which is a consequence of the conversion of electrical energy stored in the traction batteries into driving force at the wheels[4]. At full acceleration intensity, it is required to feed the full power from the vehicle's electric motor into the powertrain. The acceleration achieved depends on a number of different factors, including external conditions such as wind or external temperature, the road surface condition, weight distribution, tyre type, frontal area, and body aerodynamics, all of which directly affect energy consumption [2, 9]. When analysing the acceleration process for an electric powertrain on a level road at a given intensity, the energy supplied from the traction batteries is balanced by the sum of its expenditure to overcome the resistance to motion, including rolling (E_R) and air (E_A), powertrain losses (E_L) and also its expenditure to overcome the vehicle's inertia (E_I), which is directly proportional to the acceleration achieved [5]. The energy balance can be written as an equation (1):

$$\mathrm{E_e = E_R + E_A + E_I + E_L}. \quad (1)$$

When considering the individual components, the energy to overcome rolling resistance and air resistance, on a horizontal road, can be determined by completing a rundown test. Hence, in order to analyse the acceleration process, it is a good idea to perform a two-phase cycle, consisting of an acceleration phase immediately followed by a rundown phase. Thus, knowing the test vehicle's mass and also its deceleration during the rundown phase, the resistance to motion becomes balanced with its inertia resulting from kinetic energy. We can therefore determine the rundown energy in accordance with equation (2)

$$E_{R+A} = \frac{m\delta_w(V_1^2 - V_2^2)}{2} \quad (2)$$

where: m – road test vehicle mass; δ_w – rotating mass from the wheels; V_n – instantaneous speed of the vehicle in motion.

Similarly, by knowing the vehicle's mass and, in this case, the acceleration during the acceleration phase, we can determine the energy required to overcome the vehicle's inertia (3):

$$E_I = \frac{m\delta_w(V_1^2 - V_2^2)}{2} \quad (3)$$

where: m – road test vehicle mass; δ_w – rotating mass from the wheels; V_n – instantaneous speed of the vehicle in motion.

Electric energy (E_e) supplied to the powertrain during the acceleration phase depends on the instantaneous electrical power from the powertrain E_e when supplied with current (4) [12].

$$E_e = \int_{t_1}^{t_2} U(t) \cdot I(t)dt \quad (4)$$

where: U(t) – instantaneous voltage supplied from the traction battery to the electric motor; I(t) – instantaneous current supplied from the traction battery to the electric motor; t – time of acceleration.

Taking the above into account, it is possible to determine the efficiency of the vehicle's powertrain during the acceleration phase as the ratio of the useful energy transferred to vehicle motion (E_L) to the total electric energy supplied from the traction batterie (E_e), as shown in equation [6] (5):

$$\eta = \frac{E_L}{E_e} \quad (5)$$

At the same time, for a fixed vehicle speed, in which the acceleration is equal to 0 m/s^2, the energy balance features no inertia, thereby enabling the determination of the powertrain's efficiency under steady-state conditions.

In order to compare the different powertrains of electric vehicles, one can determine the total specific energy consumption Q_{je} expressed as the ratio of the energy output from the traction batteries to the product of the mass and the distance travelled.

$$Q_{je} = \frac{E_e}{m \cdot L} \quad (6)$$

In order to objectively address the comparison of acceleration dynamics, the authors of [7] proposed a dynamics index, which can be presented with relation (7):

$$I_D = \frac{P}{Q_E} \quad (7)$$

The proposed passenger vehicle dynamics index combines the available power of the powertrain and the specific energy consumption. This provides a versatile and objective tool for measuring traction parameters during the acceleration process. This index takes into account the powertrain's capacity, the vehicle's mass, and the distance travelled.

3. Methodology, test object, and research tools

The paper contains an analysis of a passenger vehicle's acceleration process from a fixed initial speed to a fixed final speed in a road test on a horizontal road. The final vehicle speed results from the energy balance between the powertrain and the resistance to motion, or from the vehicle reaching an assumed final speed of 120 km/h. The acceleration intensity was determined by a constant acceleration pedal use with which constant power was applied to the powertrain during the road test for a given fixed gear ratio. Each road test was repeated a minimum of three times on the same road section, driving in both directions on a given measuring section, from which mean values were taken.

The Skoda Citigo-e iV electric passenger vehicle was used during the road tests conducted as part of the author's own research. The vehicle is equipped with a proprietary measurement data recording system using the onboard data transmission network. It is a front-wheel drive electric urban vehicle with a 61 kW motor with 212 Nm of torque. The electric motor's maximum rotation speed is 12,000 rpm. The transmission system features a single gear transmission, while the total ratio is equal to i_c = 8.16. The mean energy consumption on the WLTP combined cycle is 16.4 kWh per 100 km at a range of 260 km. The car's top speed is limited to 130 km/h, and the mass during testing is 1381 kg.

An important component of the road test is the appropriate selection of the measuring section, which was a 2.2 km section with a slope of 0.05°. A proprietary measurement system developed in the LabVIEW environment was used to record the Skoda Citigo-e iV vehicle's kinematic parameters. It enables the recording of kinematic parameters in the time domain from the on-board CAN BUS-based data transmission network, recording other drivetrain parameters, such as electric motor's rotational speed, energy consumption, vehicle load and speed, battery capacity, accelerator pedal, distance, battery voltage and current, electric motor power, current to drive auxiliary equipment. In addition, a device recording GPS data – speed, acceleration, distance travelled – was used.

4. Acceleration process analysis

The acceleration process analysis was based on the measurement of the kinematic parameters of the passenger vehicle's motion in real traffic conditions on a paved asphalt surface, from a constant linear speed of 40 km/h, regardless of the selected acceleration pedal position (10%, 20%, 30%, 40%, 50%, 55%, 60%, 70%, 100%). The acceleration flexibility test for initial acceleration pedal positions was carried out until a constant speed was reached (acceleration equal to 0 m/s^2) and in other cases until a speed of 120 km/h was reached. Changes in the powertrain's basic indices during the acceleration test for the initial acceleration pedal position are shown in Fig. 1.

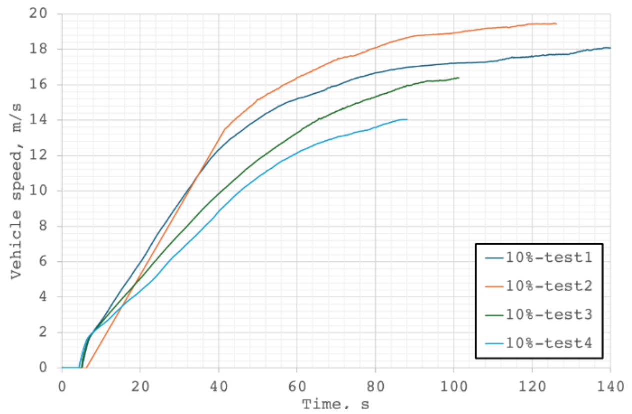

Fig. 1. Diagram of the speed vs time dependency for the 10% acceleration pedal position

Figure 2 shows the time dependence of current and energy consumption. As expected, the current increases during acceleration and then takes on a fixed value until the end of the acceleration phase. This current waveform results in a linear increase in energy consumption, while the voltage, at the same time, changes slightly from 318 V to 312 V.

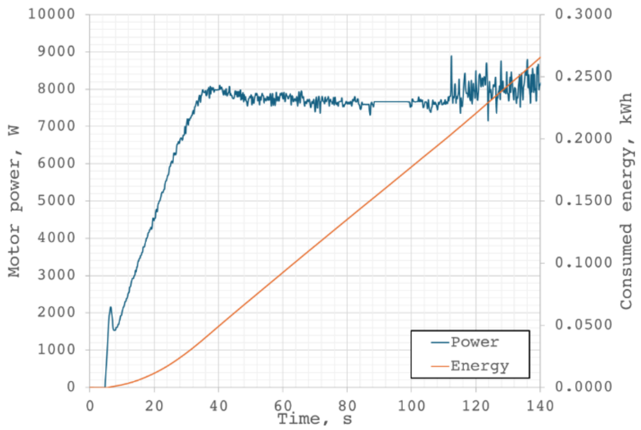

Fig. 2. Diagram of the motor power P and energy consumed E_n vs time dependency for the 10% acceleration pedal position

The acceleration tests were carried out in both directions on the road and their progression is comparable for different acceleration pedal positions, but the specific initial "peak" in the graphs for the 10% acceleration pedal position is important. It appears as soon as the acceleration pedal is depressed – the power momentarily rises to around 2.2 kW, before dropping to 1.5 kW and continuing to rise almost linearly. This is caused by the inertia in the powertrain, the so-called power jerk, which is clearly visible in Fig. 2, and also the large increase in acceleration values and their oscillation in the subsequent course (Fig. 4). Figure 3 shows the cumulative averaged waveforms from all Skoda Citigo-e iV road tests.

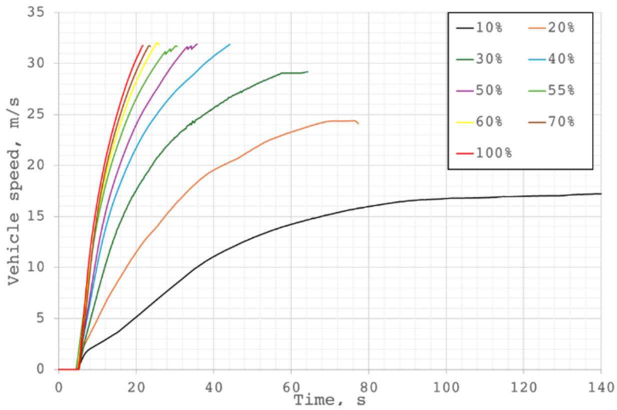

Fig. 3. Cumulative diagrams of the speed vs time dependency

The speed vs time dependency diagram in Fig. 3 shows that only in the first three runs (10%, 20% and 30% acceleration pedal positions) the road test came to an end due to the speed stabilisation and an acceleration drop to 0 m/s^2, as shown by the final acceleration waveform in Fig. 6. Despite the very slight differences in the speed profile for the acceleration pedal position of 55% and above, this recorded acceleration shows increasing values (Fig. 6), and this can be illustrated even better as a function of the change in acceleration vs speed (Fig. 7).

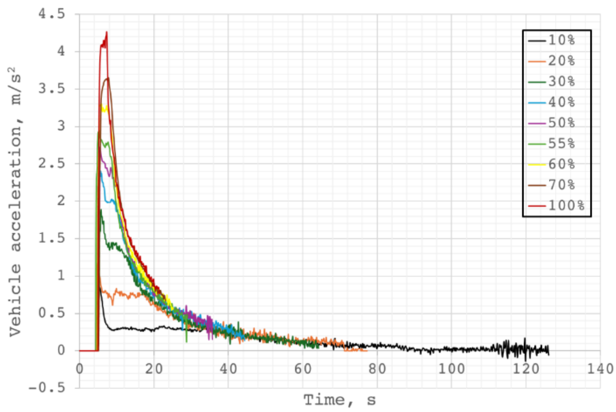

Fig. 4. Cumulative diagrams of the acceleration vs time dependency

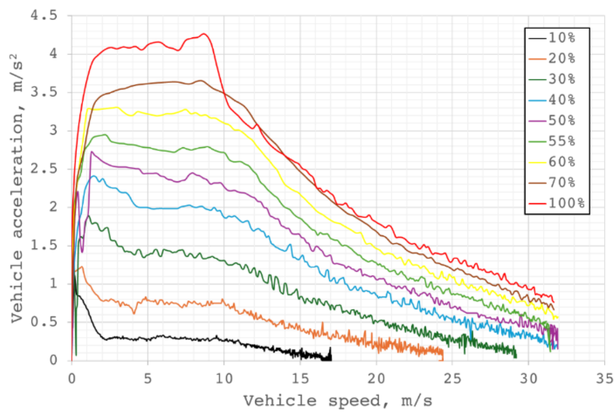

Fig. 5. Cumulative diagrams of the acceleration vs speed dependency for Skoda Citigo-e iV

Figure 5 shows that once the speed reaches 10 m/s, it starts to reduce acceleration in each case, regardless of the powertrain's set power. The higher the power value, the more intense the acceleration drop during the initial phase, and this is mainly due to the inertia and resistance to motion.

Summarising the acceleration process, the specific values of the acceleration process from its start to end can be compiled as presented in Table 1. The table shows mean power P, mean energy consumption, specific energy consumption Q_e, and others. It is worth noting that power values close to maximum power do not significantly reduce acceleration power and distance.

Table 1. Summary for driving

Pedal position	Instantaneous energy consumed E_n	Mean consumption per 100km	Mean power P	Specific energy consumption Q_e	Measurement time	Distance	Average acceleration	Maximum acceleration
%	kWh	kWh/ 100 km	kW	J/(kg·m)	s	m	m/s^2	m/s^2
10	0.18	15.7	5.8	1.5	106.8	1304	0.16	1.78
20	0.27	26.4	13.9	3.0	69	1185	0.35	2.22
30	0.35	37.7	23.3	3.3	54.7	1144	0.56	2.03
40	0.35	52.6	32.6	6.6	38.7	851	0.82	2.62
50	0.32	65.7	39.0	7.9	29.6	632	1.08	2.6
55	0.30	77.1	44.1	9.6	24.5	514	1.30	2.99
60	0.29	91.5	51.0	12.1	20.7	432	1.55	3.39
70	0.28	100.6	56.1	13.4	18.3	373	1.74	3.67
100	0.27	111.8	59.2	13.5	16.3	327	1.93	4.45

The values between the initial and maximum power increments are significant, and the difference in distance travelled between the 10% and 100% acceleration pedal position is nearly 1000 m. The mean power and specific energy consumption, on the other hand, are almost 10 times greater. The energy consumed from the battery during each test, except the first, oscillates around 0.3 kWh; the mean energy consumption increases as the distance travelled shortens considerably. Drawing attention to the energy consumed from the battery, one can observe that the car travelled a different distance in each test, preventing the use of this value to make a direct comparison between each acceleration process and partial power. Therefore, referring to Figs. 3 and 4, and Table 1, the authors further analysed a distance of 300 m and an acceleration time of approximately 16 seconds for the full power input to the powertrain. A diagram of the vehicle's speed vs road dependency for the Skoda Citigo-e iV is shown below in Fig. 6.

The values shown in Table 2 represent the mean values for the acceleration process over a distance of 300m so that an acceleration dynamics index can be calculated for an electric vehicle. The presented dependencies prove that the considered acceleration process on a shorter representative section is characterised by established dependencies in terms of available power and mean mileage energy consumption. However, the values for specific energy consumption and the calculated dynamics index indicate that once a certain acceleration pedal power value is exceeded, the index no longer increases, but only the energy consumption increases.

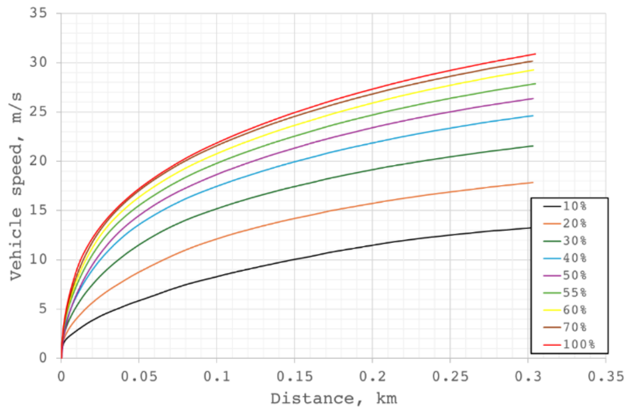

Fig. 6. Diagram for the speed vs distance travelled dependency for a 300 m distance – Skoda Citigo-e iV

Table 2. Summary for a 300 m distance travelled – Skoda Citigo-e iV

Pedal position	Instantaneous energy consumed En	Mean consumption per 100 km	Calculated mean power	Mean resistance	Mean driving power	Specific energy consumption	Measurement time	Distance	Average acceleration	Maximum acceleration	Dynamics index Id
%	kWh	kWh/ 100 km	kW	kW	kW	J/(kg·m)	s	m	m/s^2	m/s^2	kg·m/s
10	0.05	19.4	4.4	2.1	2.3	1.7	44.3	300.2	0.27	1.78	1.39
20	0.09	36.3	11.8	3.8	8.0	3.8	28.4	301.0	0.63	2.22	2.09
30	0.13	53.8	22.2	5.4	16.8	3.7	22.7	301.0	0.97	2.03	2.41
40	0.17	71.2	30.6	6.8	23.8	8.8	19.7	300.9	1.26	2.62	2.77
50	0.19	81.5	37.4	7.5	29.8	9.5	18.5	301.4	1.44	2.53	3.14
55	0.21	90.6	43.0	8.3	34.7	11.0	17.5	301.4	1.60	2.99	3.16
60	0.23	102.6	50.3	9.0	41.2	13.1	16.5	300.8	1.78	3.39	3.22
70	0.25	107.5	55.7	9.6	46.1	14.2	16.1	302.1	1.89	3.67	3.24
100	0.25	114.5	59.1	10.0	49.1	13.8	15.6	301.1	1.99	4.45	3.57

5. Passenger vehicle acceleration dynamics index

Figures 7 and 8 show graphs of the mean energy consumption and acceleration pedal position vs dynamics index dependency, according to the values shown in Table 2.

The dynamics index was calculated, which determines the energy required to accelerate a passenger vehicle with a mass of 1 kilogram over a distance of 1 metre in 1 second, based on calculations according to equation 7. According to the unit's designation, it is a value defined as per the unit of momentum. The presented dependency between the dynamics index with values such as mean energy consumption (Fig. 7) or acceleration pedal position (Fig. 8) allows for determining the moderate acceleration area associated with the energy consumption minimisation. The moderate acceleration area covers the acceleration process up to the acceleration pedal position of 40%, while the dynamic acceleration area covers the range exceeding this value. The boundary between these areas can be established based on trend lines – a point which is then projected onto the axes is established at their intersection. In the case of the diagram in Fig. 7, the limit point has a value of approximately $I_d = 3.12$ kg·m/s with an energy consumption value of approximately 80 kWh per 100 km.

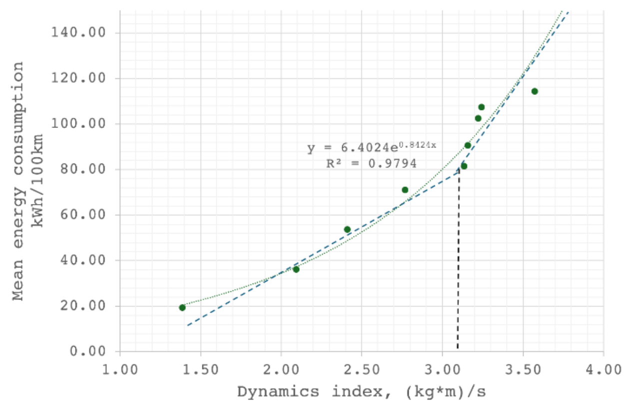

Fig. 7. Diagram of the energy consumption vs dynamics index dependency

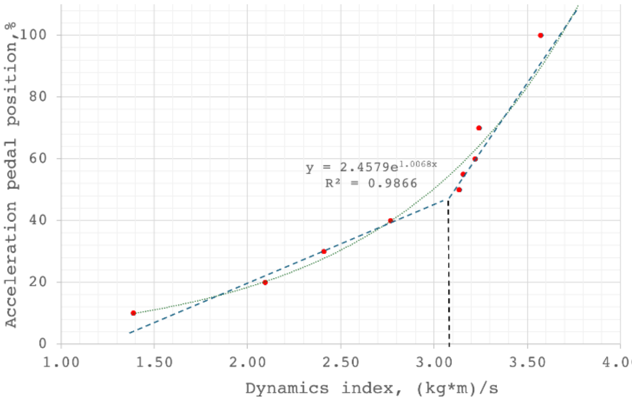

Fig. 8. Diagram of the acceleration pedal position vs dynamics index dependency

These values were compared to the results presented by the authors in paper [3] for a passenger vehicle with an indirect-injection combustion engine and a homogeneous combustion system with a power output of 110 kW, i.e. almost twice the power output of the tested electric vehicle.

A comparison of the dynamics index shows that, for both the internal combustion and electric vehicles, the moderate acceleration area occurs at no more than 40% of the acceleration pedal position. In the case of internal combustion motors, the increment in fuel expenditure is steeper in relation to the dynamics index, which takes on higher values due to the internal combustion motor's power output.

6. Conclusions

The paper presents the results of tests on the acceleration dynamics of an electric vehicle on the Skoda Citigo-e iV, with a particular focus on the effect of acceleration intensity on energy consumption in real road tests. The results show that moderate acceleration, at around 40% of the acceleration pedal position, is the most energy efficient. Further increases in power lead to a significant increase in energy consumption with a slight increase in acceleration dynamics index.

The paper introduces a dynamics index that combines the powertrain's available capacity with specific energy consumption, thereby allowing an objective comparison of the vehicles' energy and traction efficiencies. This index is a versatile tool for assessing vehicle traction performance, thereby allowing for the comparison of different powertrains. A comparison of the dynamics index with the internal combustion vehicle showed similarity in the moderate acceleration area. Acceleration as the primary phase of a vehicle's motion is a key element in the analysis of energy consumption, and the research results indicate that moderate acceleration is the most energy efficient, which is important for increasing the range of electric vehicles. The results suggest that drivers should avoid pressing the power pedal rapidly beyond 45% to optimise power consumption, which may also have a positive impact on powertrain durability and battery life. Research on the impact of acceleration intensity on the total energy consumption of electric vehicles is essential to optimise driving strategies and extend vehicle range. Understanding this relationship also supports the development of more efficient powertrain control systems.

Nomenclature

BEV	battery electric vehicle
E_R	rolling resistance energy
E_A	air resistance energy
E_I	inertia resistance energy
E_L	losses in powertrain energy
HEV	hybrid electric vehicle
ICEV	internal combustion engine vehicle
I_d	dynamics index
I(t)	instantaneous current supplied from the traction battery to the electric motor
m	road test vehicle mass
t	time of acceleration
TTW	tank-to-well
U(t)	instantaneous voltage supplied from the traction battery to the electric motor
V_n	instantaneous speed of the vehicle in motion
δ_w	wheels rotating mass

Bibliography

[1] Badin F, Le Berr F, Briki H, Dabadie J-C, Petit M, Magand S et al. Evaluation of EVs energy consumption influencing factors: driving conditions, auxiliaries use, driver's aggressiveness. 2013 World Electric Vehicle Symposium and Exhibition (EVS27). 2013;6(1):112-123. https://doi.org/10.1109/EVS.2013.6914723

[2] Berry M. The effect of driving style and vehicle performance on the real-world fuel consumption of US light-duty

Vehicles. Doctoral Thesis. 2010. https://dspace.mit.edu/handle/1721.1/58392

[3] Cieślik W, Szwajca F, Golimowski J. The possibility of energy consumption reduction using the ECO driving mode based on the RDC test. Combustion Engines. 2020;182(3): 59-69. https://doi.org/10.19206/CE-2020-310

[4] Davari MM, Jerrelind J, Trigell AS. Energy efficiency analyses of a vehicle in modal and transient driving cycles including longitudinal and vertical dynamics. Transport Res D-Tr E. 2017;53:263-275. https://doi.org/10.1016/j.trd.2017.04.019

[5] Ferreira H, Rodrigues CM, Pinho C. Impact of road geometry on vehicle energy consumption and CO_2 emissions: an energy-efficiency rating methodology. Energies. 2020;13: 119. https://doi.org/10.3390/en13010119

[6] Fic B. Samochody elektryczne (in Polish). Wydawnictwo KABE. Krosno 2009.

[7] Graba M, Bieniek A, Prażnowski K, Hennek K, Mamala J, Burdzik R et al. Analysis of energy efficiency and dynamics during car acceleration. Eksploat Niezawodn. 2023;25(1): 17. https://doi.org/10.17531/ein.2023.1.17

[8] Kropiwnicki J, Gawłas T. Evaluation of the energy efficiency of electric vehicle drivetrains under urban operating conditions. Combustion Engines. 2023;195(4):28-34. https://doi.org/10.19206/CE-169492

[9] 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

[10] Mamala J, Graba M, Stasiak P. Energy efficiency of the electric drive system of a passenger car under normal operation conditions. In: Rackov M, Miltenović A, Banić M. (eds) Machine and Industrial Design in Mechanical Engineering. KOD 2024. Mechanisms and Machine Science. 2024;174. Springer, Cham. https://doi.org/10.1007/978-3-031-80512-7_90

[11] Shuklinov S, Uzhva A, Lysenko M, Tishenko A, Novikova Y. Maximum automobile acceleration. Automobile Transport. 2021;49:13-22. https://doi.org/10.30977/AT.2219-8342.2021.49.0.02

[12] Siłka W. Energy consumption of car movement (in Polish). WNT. Warszawa 1997.

Mariusz Graba, DEng. – Faculty of Mechanical Engineering, Opole University of Technology, Poland.
e-mail: *m.graba@po.edu.pl*

Krystian Hennek, DEng. – Faculty of Mechanical Engineering, Opole University of Technology, Poland.
e-mail: *k.hennek@po.edu.pl*

Prof. Jarosław Mamala, DSc., DEng. – Faculty of Mechanical Engineering, Opole University of Technology, Poland.
e-mail: *j.mamala@po.edu.pl*

Krzysztof Prażnowski, DEng. – Faculty of Mechanical Engineering, Opole University of Technology.
e-mail: *k.praznowski@po.edu.pl*

Maximilian Mueller, MEng. – student at Opole University of Technology, Poland.