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ENERGY CHARACTERISTICS OF CITROEN BERLINGO CONVERTED TO ELECTRIC VEHICLE

Summary. This report introduces the study results of a Citroen Berlingo converted into an electric car. It presents the energy properties of road and laboratory tests. Initially the structure of the converted car is described, and characteristics of the main car elements are given. Then, the power and energy characteristics of the converted car are obtained and analyzed. On the road, energy consumption at different constant speeds is registered. In addition, at laboratory, the energy consumption during the Special Cycle for Electric Vehicles and Driving Cycle ECE-15 has been obtained. A comparison of the energy consumption of the studied car and serial BEV was done, and it shows good energy efficiency of the converted car during the driving cycles.

1. INTRODUCTION

In search of solutions for the energy crisis of the last century [2, 3, 4, 6] and the impact of transport on global warming [5, 9,], there has been an increasing interest in the production and putting into operation a growing number of electric vehicles [1, 8, 10].

One way to speed up this process is to convert cars [8, 10, 13], where the ICE and its accompanying systems are removed from conventional vehicles and an electric propulsion system is installed in their place. The conversion of such an electric vehicle depends on the vehicle's drive scheme [11, 13].

The testing of the car energy characteristics is possible in real road conditions or in the laboratory, on the testing benches [7, 12]. Usually the results from road and laboratory tests have some difference.

For laboratory test, concerning energy consumption, the driving cycles can be applied [7]. There are generally accepted driving cycles for conventional cars, such as ECE 15, and special cycles for electric vehicles. Results obtained under the first one cycle allow to compare energy consumption of the electric end conventional cars [7, 12].

The second cycle is specially developed for electric cars and can be used for comparative analysis only between these types of cars [7].

The aim of the present paper is an experimental study of the energy properties of a converted Citroen Berlingo to electric vehicle. Laboratory and road characteristics regarding the energy consumption of the electric vehicle were obtained.

2. EXPOSITION

Citroen Berlingo 2005 is available in three versions: passenger, wagon and station wagon. The transport vehicle in its varieties is suitable for a family van and for work. The basic parameters of the car are presented in Tab. 1 [15].

When converting the vehicle, the internal combustion engine has been dismantled and a synchronous motor with constant magnet excitation and the necessary control systems have been installed in its place. A lithium-ion battery has been installed in the luggage compartment to store electricity.

The electric car is equipped with an electric motor EM253-25 (PMSM) 25 *kW* with a nominal torque of 85 *Nm* at normal load and 170 *Nm* when overloaded. Fig. 1 shows the general view of the electric motor, and Fig. 2 shows its external speed characteristics. It shows that the electric motor stands a double overload and maximum power is reached at 2800 min^{-1}.

Table 1

Basic technical characteristics of *Citroen Berlingo*

Overall Length/ Width Height , *mm*	4137 / 1724 / 1819
Driving axle	Front
Longitudinal base, *mm* Distance between wheels front / rear, *mm* Ground clearance, *mm*	2693 1420 / 1440 140
Drag coefficient (streamlining)	0,37
Transmission	Mechanical
Number of gears	5
Transmission numbers of the box:	3,636; 1,95; 1,281; 0,975; 0,767;R 3,583
Central gear	4,54
Tires	175/70 R 14 T

Fig. 1. General view of the PMSM electric motor

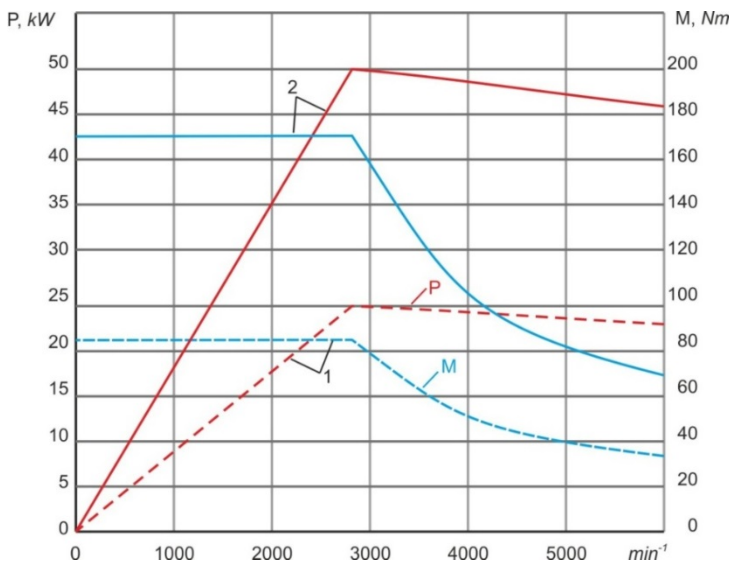

Fig. 2. External speed characteristic of the PMSM electric motor: 1 – nominal characteristic of the electric motor; 2 – characteristic at overload

The rechargeable battery for propulsion of the electric car consists of 48 rechargeable cells: SINOPOLY – SP-LFP-100AHA – 153,6 *V*, 100*Ah*. The controller for the electric motor is CURTIS 1239E. The mass of the converted electric car is 1360 *kg*. The full weight at which the trials have been performed is 1620 *kg*. The layout of the converted electric vehicle is shown in Fig. 3.

The preparation of the electric car and the conditions under which the driving cycle tests have been carried out meet the requirements described in UN-ECE-R101-Fuel-Consumption [12].

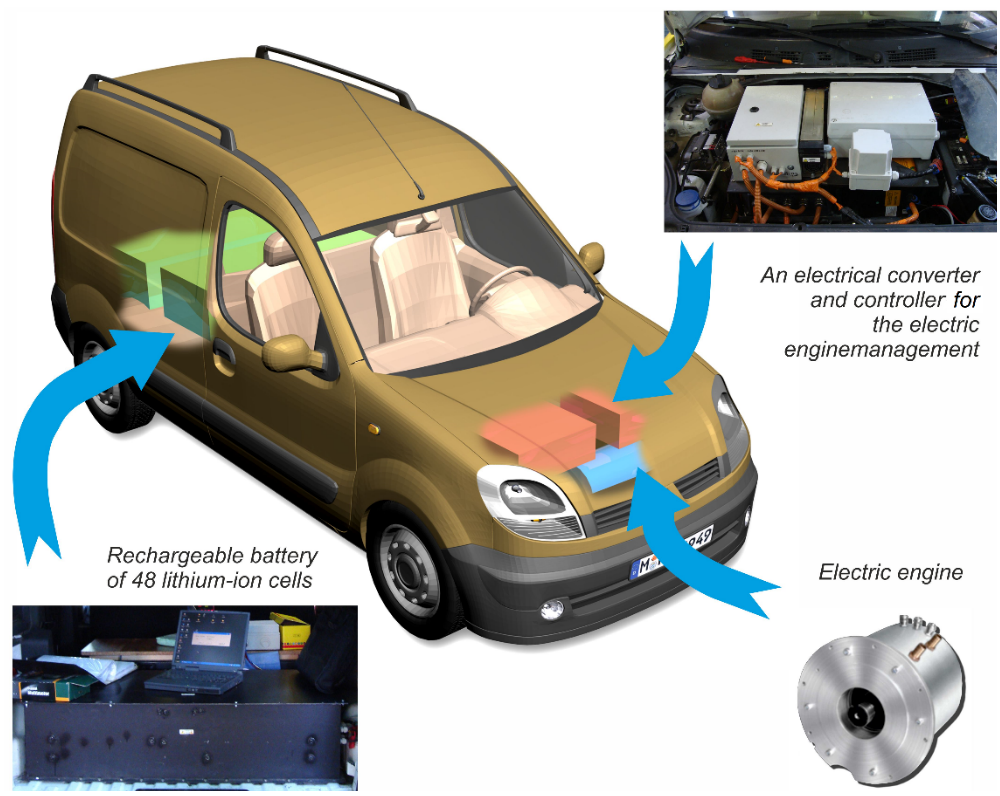

Fig. 3. Layout of the converted electric vehicle

The RAM XII automobile roller power stand manufactured by SUN (Fig. 4.) was used in the laboratory tests. The range of the stand is up to 200 kW vehicle power, with up to 200 km/h top speed.

A tracking wheel of the company "Peiseler" (Fig. 5) with a DB Print device is used to conduct the road experiments. The traducer of the tracking wheel gives 500 impulses per a turn (distance) of 2.16 m. The accuracy of speed measurements is less than 0.2%.

For registering the electrical quantities during conducting laboratory and road tests, a multi-channel measuring and recording system "VITTEL PRO" (MIRSES-VITTEL PRO) is used. The accuracy for measurements of currency is 0.1 A and for voltage – 0.5 V. It registers all the energy consumption from the traction battery during experiments.

3. METHODOLOGY TO DETERMINE POWER CONSUMPTION BY GEARS

During the experiments, the electrical data are recorded during movement at a given gear. In determining the power consumption, the measurements are made in three operating rotation speeds of the electric motor of 1400, 2400 and 4200 min^{-1} at each gear. During the road tests, the electric vehicle moves at a constant speed on the measured track under the same operating rotation speed of the electric motor. For road and laboratory tests, the recording of the equipment starts out for about 30 seconds after the required steady speed has been reached and established.

The energy and power characteristics are built on experimental data about electrical parameters recorded each second with a measuring equipment. Using values of the current and the voltage consumed, power was calculated. Then using value of the respective constant speed for experiment, the consumed energy in *kWh/100km* was calculated. As the measurement concerns the battery, calculated power and energy consumption include also consumption of the auxiliary systems (dashboard panel, battery level indicator, etc.).

Fig. 4. General view of the laboratory test facility SUN RAM XII

Fig. 5. The tested electric vehicle, equipped with a Peiseler tracking wheel and DB print (in the cab)

4. RESULTS FOR THE ENERGY PROPERTIES OF AN ELECTRIC VEHICLE

4.1. Determination of electricity consumption in road and laboratory conditions

Results for energy consumption during driving an electric vehicle are shown in Fig. 6 and 7. Fig. 6 shows that in the range of 30 to 60 *km/h,* the energy consumption is the lowest. This range is characteristic of urban traffic conditions. Gears that can achieve this speed are from 2 to 5 inclusive.

Fig. 7 shows the average energy performance. The range of speed in which the electric vehicle consumes the least energy is well represented - 9.5 *kWh/100 km* at a speed of 50 to 55 *km/h*.

Energy characteristic, obtained on a power stand RAM XII, is shown in Fig. 8. It represents well enough the speed range of 45 to 50 *km/h*, where the electricity used by the electric car is the lowest - 11.25 *kWh/100 km*.

In Fig. 9, the average laboratory energy characteristic is presented. Here one can see the range of speed in which the electric car consumes the least energy - 10.5 *kWh/100km* at a speed of 55 to 65 *km/h*.

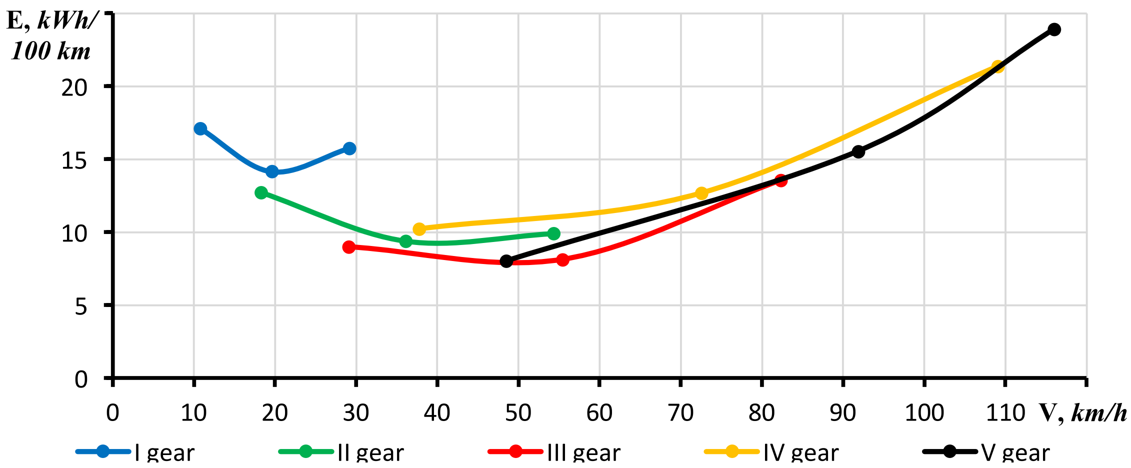

Fig. 6. Energy characteristic on the road by gears

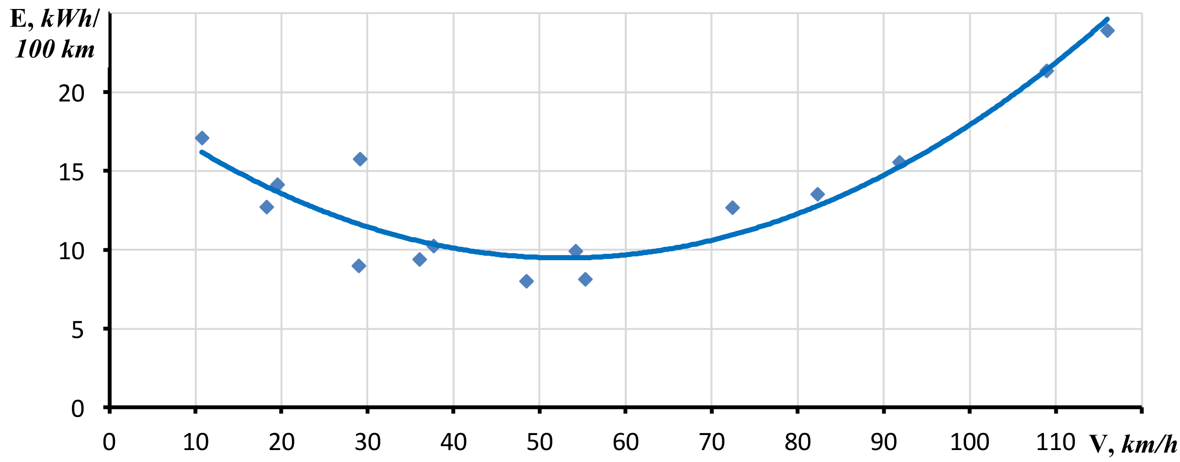

Fig. 7. Average energy characteristic on the road

A comparison between the averaged road test and laboratory energy characteristics is done in Fig. 10. It indicates that the consumed electricity for the experimental road characteristic is the lowest at 55 *km/h,* with value of 9.5 *kWh/100 km* (95 *Wh/km*), and for the laboratory tests, at about 65 *km/h,* with value of10 *kWh/100 km* (100 *Wh/km*).

The concurrence between laboratory and road results is very good at high and medium speeds. At low speed, the difference is quite significant - it reaches 27%. In the computer of the laboratory test, bench uses the same values of the drag coefficient – 0.34 and for rolling resistance coefficient – 0.015, which were experimentally obtained on the road conditions. The difference of the results is due to the stronger influence of the different tire deformation on the rollers of the bench compared to the deformation on flat road surface at low speed.

A comparison between road and laboratory energy characteristics by gears is illustrated on Fig. 11. The difference between laboratory and road results is higher at low speed - I and II gear. In III, IV and V gears, the concurrence is good. The curves of the two characteristics have a similar shape and layout. The higher relative consumption at I and II gears is clearly expressed.

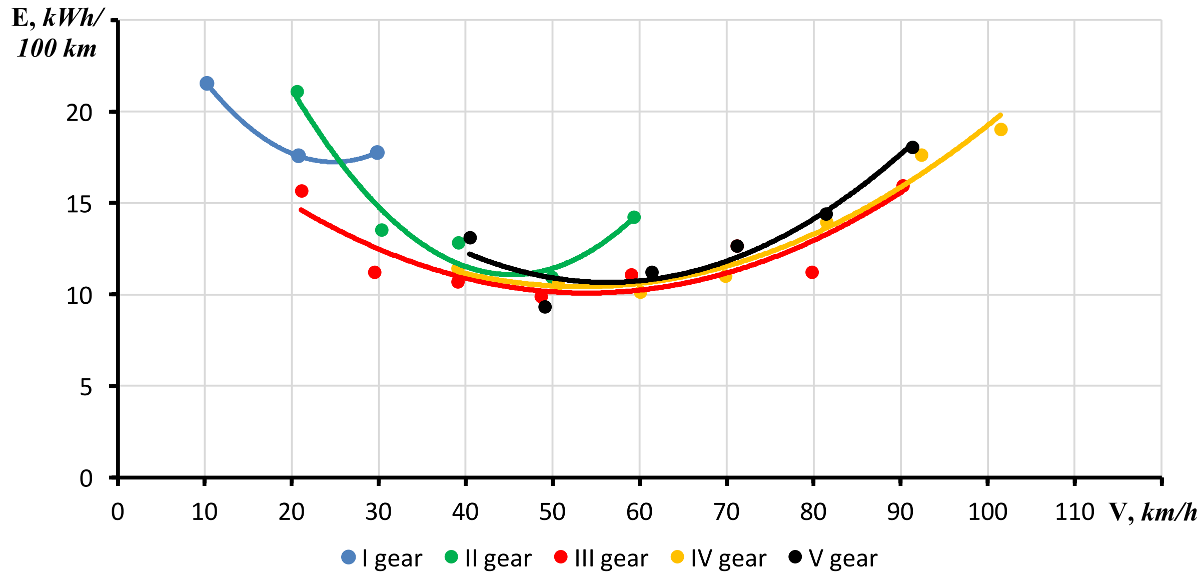

Fig. 8. Laboratory energy characteristic by gears

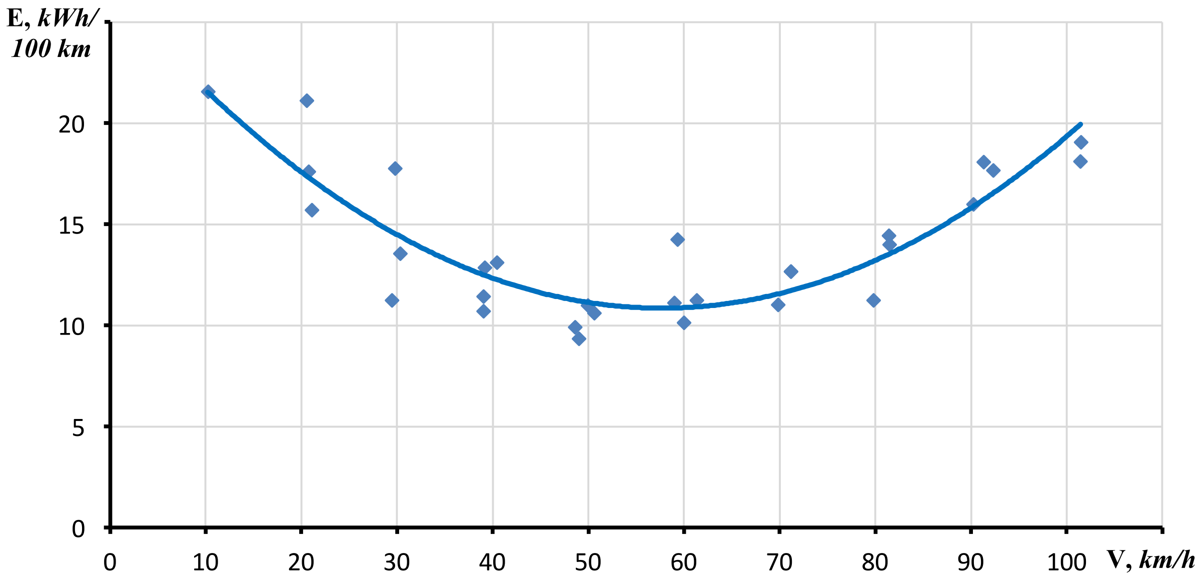

Fig. 9. Average energy characteristic in laboratory tests

The comparisons between speed ranges with the lowest power consumption and the gears at which it can be achieved for road and laboratory energy performance are presented in Tab. 2. The range of the laboratory characteristic is slightly higher than the road, but here too the reason is the stronger influence of the different tire deformation on the roller of the bench compared with the flat road surface.

Table 2

Speed ranges with the lowest energy consumption

Characteristic	Range, *km*	Gear
Road	30–60	III–V
Laboratory	40–65	II–V

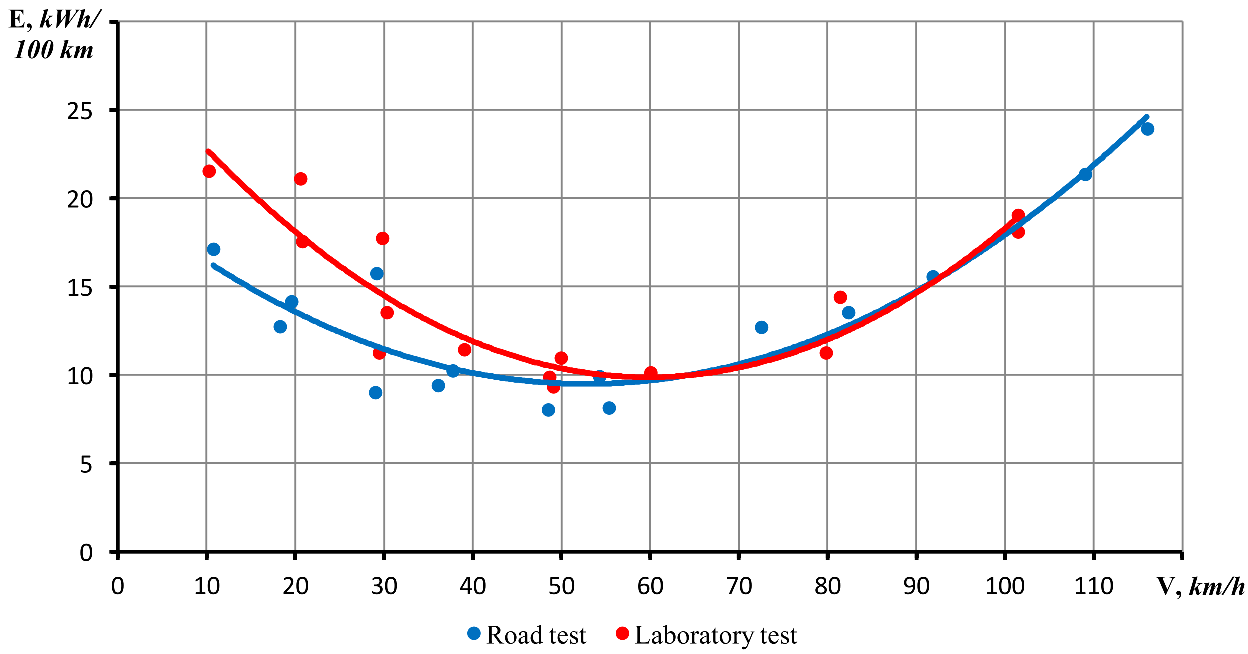

Fig. 10. Comparison of average laboratory and road energy characteristics of the electric car

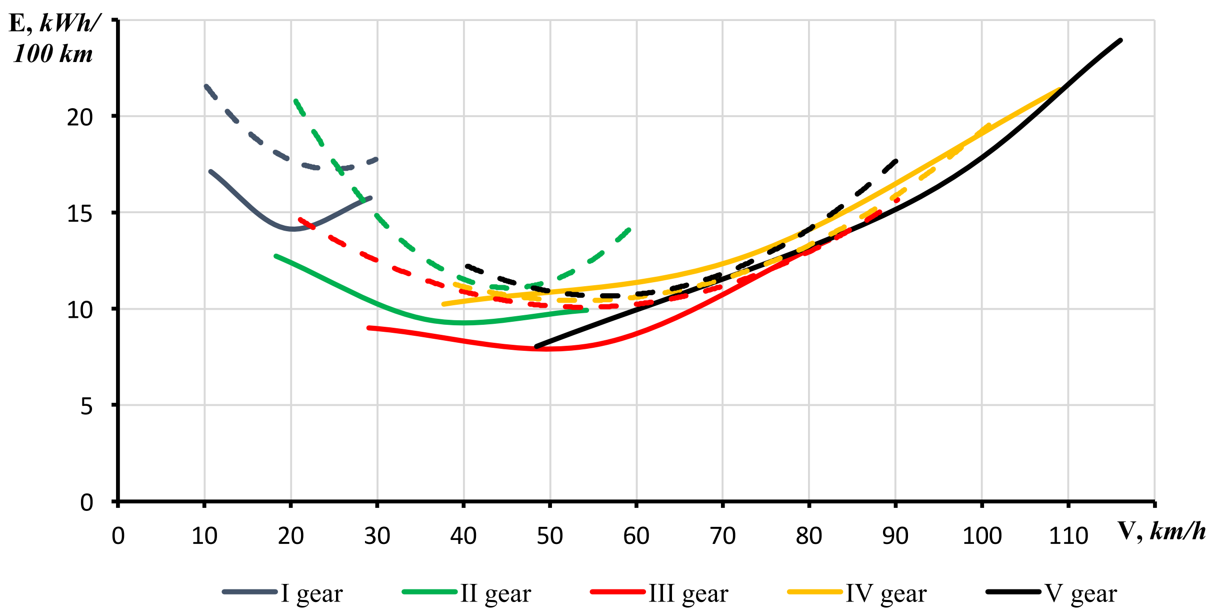

Fig. 11. Comparison between energy characteristics of the converted electric car by gears: road characteristic; laboratory characteristic

Fig. 12 shows the laboratory and road power characteristics. It can be seen that a power of respectively approximately 19 *kW* and 18 *kW* is required to achieve a speed of 100 *km/h* with the defined mass of the electric vehicle. In urban driving conditions, the necessary power output of the electric motor is approximately 7 *kW* and respectively 6 *kW* in order to reach a speed of 60 *km/h*. The difference between laboratory and road results is at low speed, but generally the concurrence is very good.

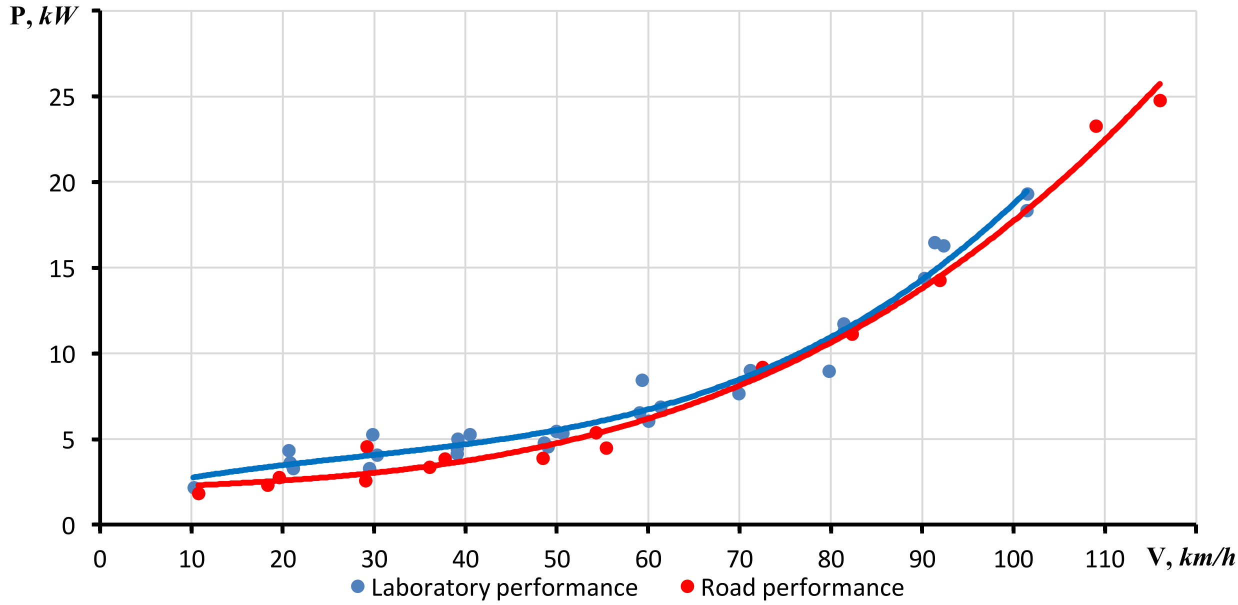

Fig. 12. Road and laboratory power characteristics

4.2. Study results of energy properties in driving cycles

A study of the energy consumption has been performed over two cycles - the special cycle for electric vehicles SAE J227a-C [14] and the European driving cycle ECE-15 which is also useful for small BEV. The results are presented in Tab. 3 and 4. The results for one test of energy consumption in the Special Cycle for Electric Vehicles are presented graphically in Fig. 13. The results for the European driving cycle ECE-15 are presented in Fig. 14. Using the cycle ECE-15 in tests gives the possibility to compare energy consumption of the tested car with existing data [6, 7] for corporate BEV (see Tab.5)

Table 3

Energy consumption in the special driving cycle for electric vehicles

Element №	Average speed, *km/h*	Distance, *км*	Energy consumption of the element in the cycle, *Wh*	Total energy consumption per cycle, *kWh*	Relative power consumption, *Wh/km*
1	31,8	0,529	157	0,679	308,8
2	33,6	0,570	174		
3	32,8	0,555	176		
4	32,7	0,545	172		

Table 4

Energy consumption in the Car driving cycle ECE-15

Element №	Average speed, *km/h*	Distance, *km*	Energy consumption of the element in the cycle, *Wh*	Total energy consumption per cycle, *kWh*	Relative power consumption, *Wh/km*
1	21,2	1,10	315	1,247	284,7
2	21,7	1,10	311		
3	21,2	1,06	307		
4	22,4	1,12	314		

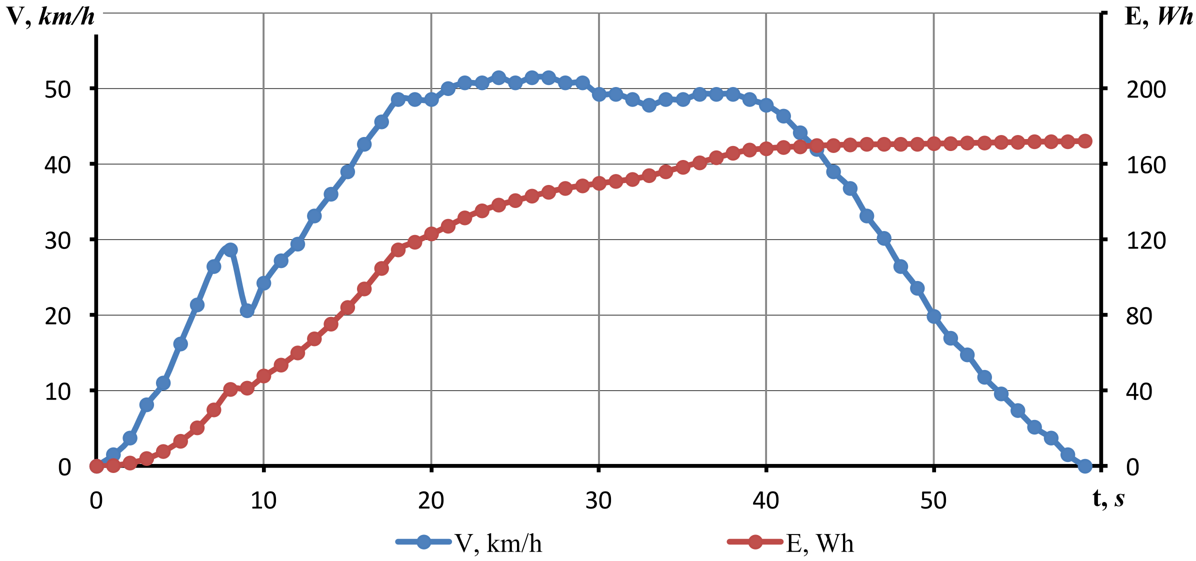

Fig. 13. Energy consumption during one of the tests - Special Cycle for Electric Vehicles

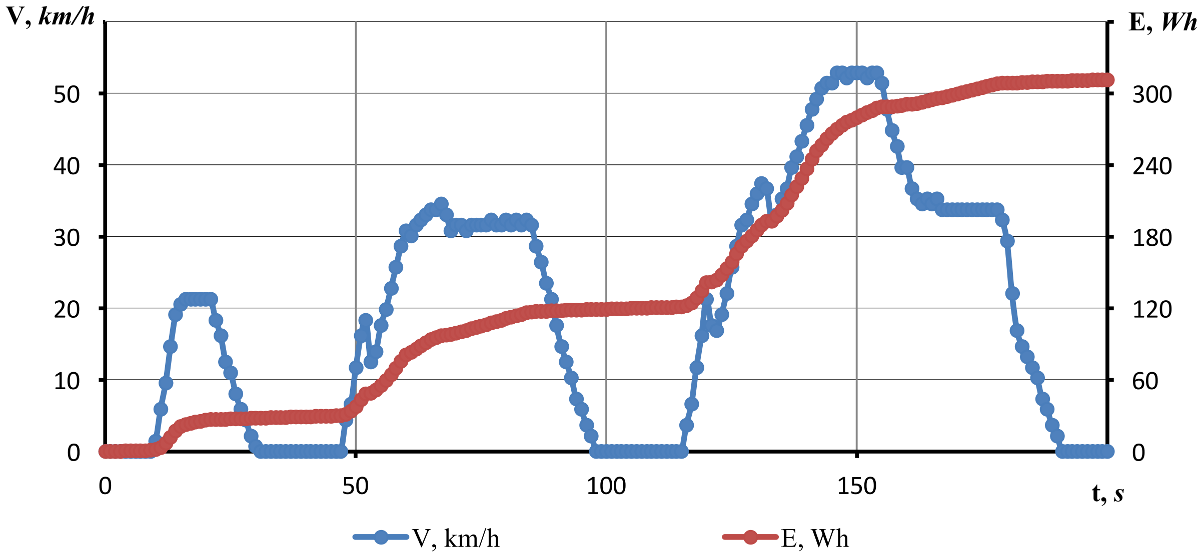

Fig. 14. Energy consumption during one of the tests - European driving cycle ECE-15

Research results show that the electric vehicle has a specific power consumption of 308.8 *Wh/km* for the special driving cycle for electric vehicles and 284.7 *Wh/km* for the ECE-15 cycle. These results (1,247 *kWh* for the ECE-15 cycle) are very good for an electric car with the technical data as the tested one. Corporate electric car models with similar power and mass are TH!NK City, Mitsubishi MiEV and FIAT Phylla (Tab. 5, rows in shadow). Compared to those for corporate electric cars [6,7] (Tab. 5), the energy consumption of the tested electric vehicle is lower than that one of similar models with 12.2 – 43.3%. However, the conclusion cannot be very categorical, because electric vehicles are tested in different laboratories, with different equipment (diameter of the power stand rollers and values of the drag and rolling resistance coefficients can be different). The comparison of energy consumption indicates that the selection of the electric motor and the battery of converted vehicle is properly made.

Table 5
Energy consumption in ECE-15 for electric vehicles with lithium rechargeable batteries and difference in comparison with converted car Citroen Berlingo

№	ELECTRIC CAR	MASS, *kg*	MAXIMUM POWER, *kW*	ENERGY CONSUMPTION PER CYCLE, *kWh*	DIFFERENCE OF ENERGY CONSUMPTION, %
1.	Mitsubishi MiEV	1370	47	1,96	36,4
2.	Renault ZE BE BOR	1881	44	2,71	54,0
3.	Mini E	1615	47	2,07	39,8
4.	TH!NK City	1547	30	2,20	43,3
5.	FIAT Phylla	970	27	1,42	12,2
6.	DuraCarQuicc!	1640	50	2,43	48,7
7.	TESLA Roadster	1385	184	1,99	37,3
8.	Protoscar LAMPO	1530	200	2,19	43,1

5. CONCLUSIONS

Data about the energy characteristic/performance of an electric car has been obtained via road and laboratory experiments by gears. The electric power consumption for the electric vehicle in the Special Cycle for Electric Vehicles and Driving Cycle ECE-15 has been found. From the analysis of the obtained results, the following conclusions can be drawn:

1. From the road energy characteristic, the lowest energy consumption has been determined to be at 55 *km/h* - 9.5 *kWh/100 km*.
2. The laboratory energy characteristic is very close to the road at medium and high speed. At low speed, the difference reaches 27%. The reason is the stronger influence of the different deformation of the tire on the rollers of the bench compared to the flat road surface at low speed.
3. From the comparison of the average laboratory and road power characteristics, it is understood that to achieve a speed of 100 *km/h* with the defined mass of the electric car, the necessary engine power is about 19 *kW* and 18 *kW,* respectively. For a speed of 60 *km/h,* the required electric motor power is about 7 *kW* and 6 *kW,* respectively.
4. The study performed under the Special cycle for electric vehicles and the Test driving cycle ECE-15 found that the electric vehicle has 12.2 – 43.3% better energy properties compared with power equivalent models of brand cars. The conclusion cannot be very categorical, because electric vehicles are tested in different laboratories and with different equipment.

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