INFLUENCE OF BATTERIES WEIGHT ON ELECTRIC AUTOMOBILE PERFORMANCE

Dainis Berjoza, Inara Jurgena
Latvia University of Agriculture
dainis.berjoza@llu.lv, inara.jurgena@llu.lv

Abstract. Modern electric automobiles tend to have greater battery capacities. Battery packs with an average capacity of 16-22 kWh were used at the initial stage of manufacturing serial electric vehicles. A number of new models of electric vehicles are equipped with batteries, the capacity of which exceeds 30 kWh, which can result in a significant increase in the basic weight of the electric vehicle. Any increase in the weight can lead to an increase in energy consumption per km travelled. The present research developed a methodology for determining the range and dynamic parameters of electric vehicles depending on changes in the basic weight of the vehicles. The present research also calculated the effect of changes in the weight for various serial electric automobiles.

Keywords: battery weight, electric automobile range, battery capacity, energy consumption, electric automobile dynamics.

Introduction

Due to the need to reduce CO_2 emissions, the EU's climate protection programmes introduce support for alternative energy vehicles and related infrastructure. Electric automobiles are one of the kinds of alternative energy vehicles. Even though the first electric automobiles emerged along with internal combustion vehicles, i.e. more than 110 years ago, the electric automobiles have not become popular. The key reason that prevented electric automobiles from being broadly introduced was their heavy batteries and the relatively limited autonomy per charge. The reason of their relatively limited autonomy was the relatively low density of energy stored in the batteries, compared with the amount of energy available in liquid fuel. Electric automobiles were referred to many times during the evolution of auto transport, yet they were usually manufactured in small experimental series and were mainly custom-made.

First hybrid technology automobiles were introduced at the beginning of the 21st century, and later electric automobiles appeared as well. However, the key disadvantage of electric automobiles, just like it was 110 years ago, was the relatively heavy battery packs that did not allow considerably increasing the travel range of the electric automobiles. A lot of funds were invested in the fields of science related to the development of battery technologies for electric automobiles; however, at present, no very light and cheap batteries that, in terms of the weight and energy capacity, are equivalent to the fuel tank of internal combustion automobiles have been designed. For this reason, the buyers of electric automobiles need to choose the automobiles meeting the necessary operational conditions, one of which is the travel range per charge. An essential aspect in purchasing an electric automobile is the price of it [1].

Research on the effects of the weight of batteries of an electric automobile and of the total weight of the electric automobile on its performance parameters is very urgent. In designing a greater capacity fuel tank for an internal combustion engine automobile, auto manufacturers only risk decreasing the free space of the automobile. When operating such an automobile, the user has a free choice – to operate it with a full or a half-empty tank, especially in a situation where daily kilometrage is small. In the case of an electric automobile, the battery pack installed on the electric automobile has to be transported all the time, regardless of the average daily kilometrage.

One of the parameters to be easily calculated based on the technical characteristics of an electric automobile is energy consumption per km travelled. For modern electric automobiles, this parameter is in a very broad range of 67.8- 216.7 $Wh \cdot km^{-1}$, which indicates that, in terms of economical fuel consumption, electric automobiles of various models may differ more than threefold [2].

Modern electric automobiles are equipped with lithium-ion batteries. The most popular battery capacity is 20-22 kWh. The weight of batteries is increased by extra elements, e.g., the battery management system, the cooling and safety system as well as the assembly box for battery modules. In view of the elements of the battery system, its cost can reach 1 $EUR \cdot (Wh)^{-1}$[3].

The travel range of modern electric automobiles is in the range of 60-450 km, according to the NEDC test cycle [2]. The volume occupied by batteries is also large, reaching 0.1-0.6 m^3 [4].

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Using lithium-ion batteries in electric automobiles the weight of the battery system necessary for traveling 100 km can exceed 150 kg. For limousine-class electric automobiles, the travel range of which is more than 300 km, the weight of batteries could exceed 500 kg [4]. This is one of the reasons why auto manufacturers are not eager to considerably increase the capacity of battery packs to above 30 kWh. A medium-class electric automobile equipped with 1.1 kWh batteries can cover, on average, a distance of 8 km [5]. A number of researchers suggest using the plug-in technology, as the cost of the battery system for such vehicles could be considerably decreased, as well as there is no need to worry about energy exhaustion after the battery has been fully discharged [6]. Optimum parameters may be chosen by performing a simulation for hybrid automobiles equipped with battery packs and electric motors of various capacities [6].

Compact-class electric automobiles are usually intended for urban driving, and they are not equipped with high-capacity battery packs. If compared with internal combustion automobiles of the same class, electric automobiles are usually heavier by 10-15 % [2; 7].

Materials and methods

Modern electric automobiles vary within a broad range in terms of battery weight, battery capacity and electric automobile weight. Electric automobiles of 30 various models were selected for a further analysis. A few of the electric automobile models examined were equipped with batteries of various capacities. In the further analysis, the capacity of batteries for these electric automobile models is specified in parentheses behind the model. The weight of batteries and the gross weight of electric automobiles available in the market and exploited in Latvia are presented in Figure 1.

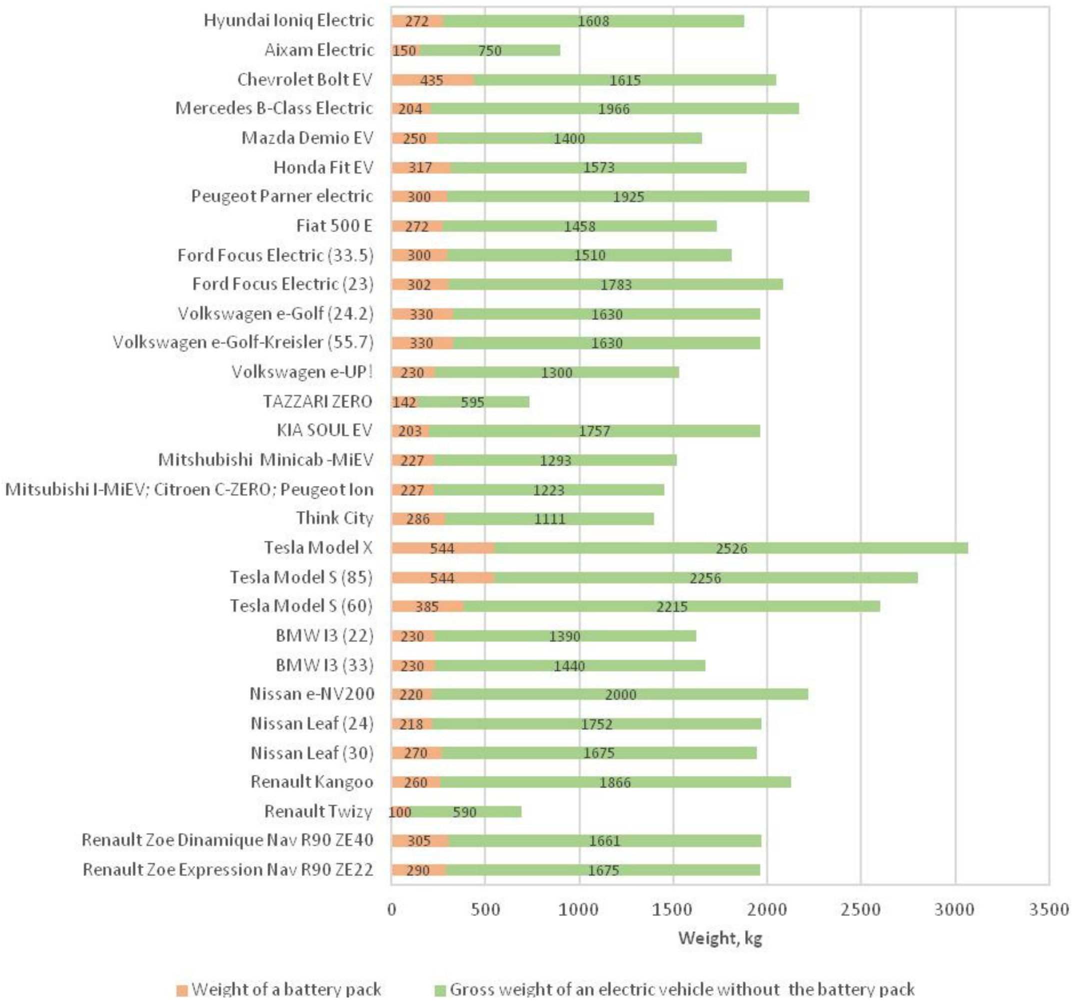

Fig. 1. **Weights of selected electric automobiles and their battery packs**

The analysed electric automobiles may be classified into two categories by the number of seats: two-seat and five-seat. Two-seat electric automobiles are equipped with lower capacity batteries (6.1-

12.3 kWh), the weight of which is in the range of 100-150 kg. An exception is electric automobiles Think City that are equipped with a 23 kWh battery pack weighing 286 kg. The weight of batteries of higher capacity (60-100 kWh) for electric automobiles is in the range of 385-544 kg, while the gross weight of the automobiles is in the range of 2050-3070 kg. Tesla electric automobiles, which are equipped with high capacity batteries, have the highest gross weight. Medium-class electric automobiles of the latest modifications tend to have lower weight batteries of the newest generation, e.g., the 2017 model of Renault Zoe is equipped with a 41 kWh battery pack of the new generation, which is only 15 kg heavier than the 22 kWh battery pack of the previous generation [2].

Specific energy consumption, measured in $Wh \cdot km^{-1}$, has been analysed in detail in other research papers [2]. According to the research data, the best performers were compact and light electric automobiles, the weights of batteries of which were low, e.g., Renault Twizy – 67.8 $Wh \cdot km^{-1}$ and Tazzari Zero – 87.9 $Wh \cdot km^{-1}$. The highest energy consumption was specific to the following electric automobiles: Tesla Model S (85) with 199.5 $Wh \cdot km^{-1}$ and Kia Soul EV with 216.7 $Wh \cdot km^{-1}$. The consumption of energy by the mentioned electric automobiles is high, and in a few countries, where electricity prices are high or charging costs at public charging stations are high, the cost of electrical energy can approach the fuel cost of the most economical internal combustion automobiles [2].

The effects of the weight of an automobile on its performance is presented in Figure 2.

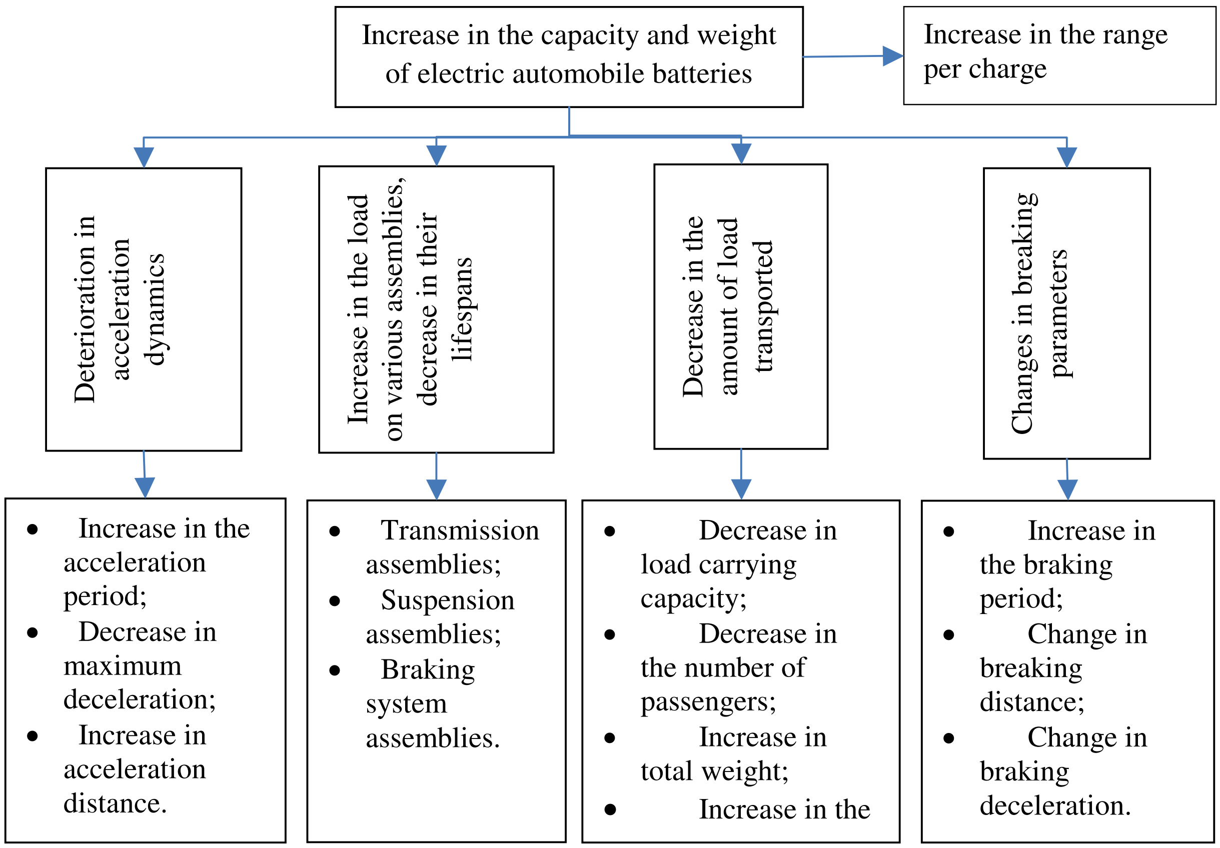

Fig. 2. **Effects of the weights of an automobile on its performance parameters**

Those converting internal combustion engine automobiles into electric ones may deal with the weight increase parameters analysed. If the purpose of conversion is to achieve a range of more than 150 km for the converted automobile, but it is not intended to increase the basic weight of the automobile, the task is difficult to perform, as the weight of the batteries can reach 250 kg. The total weight of other assemblies used in the conversion (electric motor, inverter, fastening frames and other assemblies) can reach 80-90 kg.

Results and discussion

An in-depth analysis was performed for the electric automobiles that were equipped with different capacity batteries in order to precisely identify the effects of the battery weight on the travel range.

Theoretically, a twofold increase in the battery capacity should result in a twofold increase in the range. Unfortunately, such a causal relationship is not in force, as an increase in the battery capacity of an electric automobile considerably increases inertial masses that hinder the acceleration of the automobile. The characteristics of electric automobiles of the same model and design, which are equipped with different capacity batteries, are presented in Figure 3.

The automobile Renault Zoe with 41 kWh batteries is equipped with the batteries of the new generation, the capacity of which is 86 % higher than that for the previous generation batteries, while the basic weight of the automobile is only 10 kg higher. In this case, the range increases considerably, up to 70 %. A similar trend is observed for the electric automobile BMW I3 – a 50 % increase in the battery capacity increases its range by 95 %. Increasing the battery capacity by 41 % for the electric automobile Tesla Model S, its range increases by only 15 %. Such a trend is typical of the electric automobiles using batteries of the same technology to increase the capacity of the batteries.

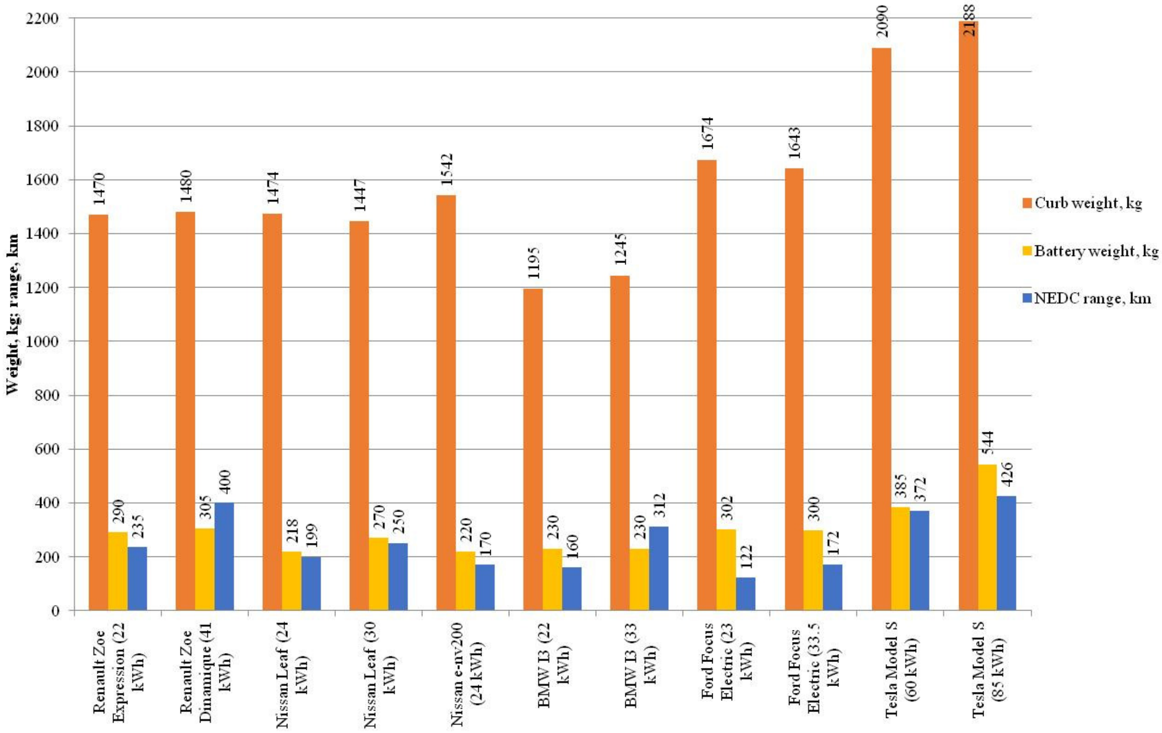

Fig. 3. **Battery capacities, gross weights and ranges of electric automobiles according to the NEDC cycle**

A causal association between the battery weight and energy consumption for the electric automobiles analysed is presented in Figure 4.

Among the electric automobiles analysed, the Renault Zoe with the lowest capacity batteries, 94 Wh·km^{-1}, had the lowest energy consumption. Similar energy consumption was observed for the electric automobiles Renault Zoe (41) and BMW (33), 103 and 106 Wh·km^{-1}, respectively. The highest energy consumption was found for the electric automobile Tesla Model S – 200 Wh·km^{-1}.The Ford electric automobiles also demonstrated high energy consumption. A comparison of the electric automobiles allows concluding that the heaviest high-comfort class electric automobiles have even twofold higher energy consumption than compact class electric automobiles.

Methodology of the experiment

To examine a change in the weight of an electric automobile, an experiment was done on the automobile. The trials imitated an increase in the battery weight by 270 kg. This was the average battery weight for electric automobiles with a battery capacity of 22-24 kWh, which was calculated based on the technical characteristics of 12 diverse serial electric automobiles [2].

The trials used an electric automobile Fiat FiorinoElectrico. The key technical characteristics of it were as follows:

- nominal power of engine 30 kW, maximal power (peak) 60 kW;
- brakes – energy recovery;
- charging – 230 V – 16 A;
- battery – lithium 21.1 kWh;
- maximum speed – up to 100 km·h^{-1};
- range-100 km.

A scientific radar Stalker ATS was used to determine the automobile's acceleration parameters. The technical characteristics of the radar were as follows:

- measuring speed range1 – 480 kmh^{-1};
- speed accuracy- ±1.00 kmh^{-1};
- time accuracy- 0.01 s;
- weight- 1.45 kg.

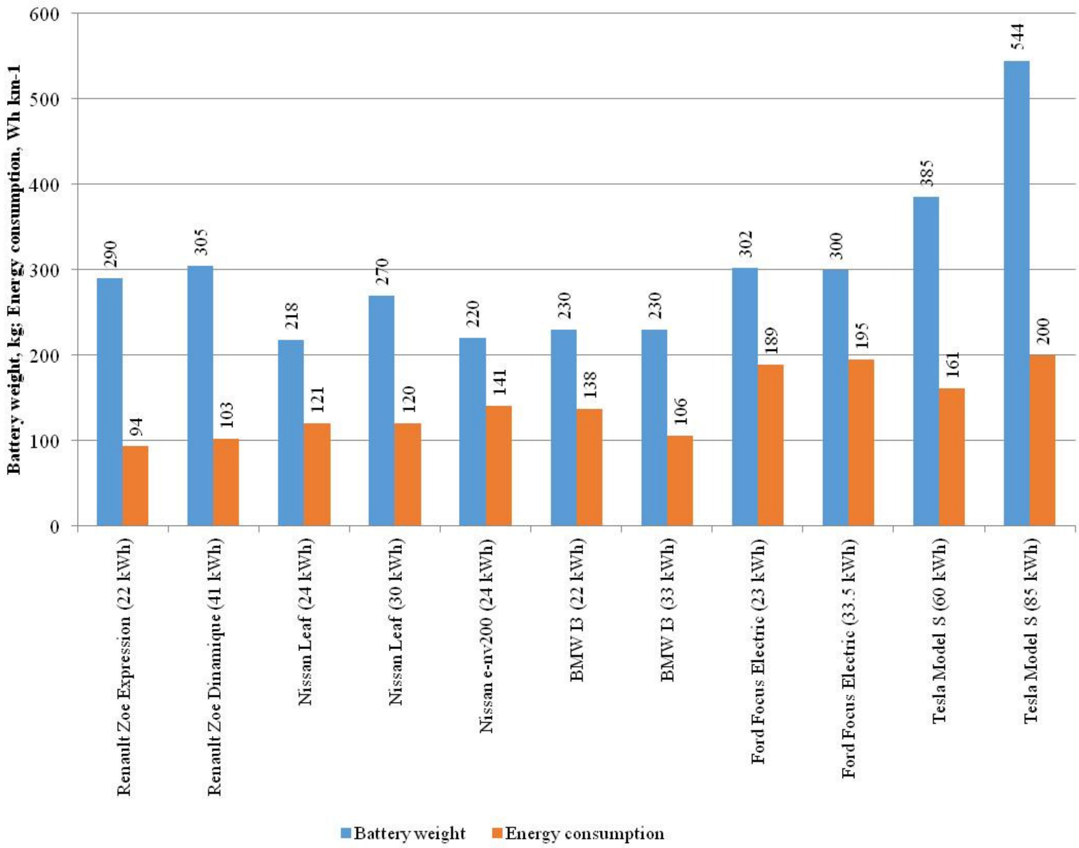

Fig. 4. **Battery weights and energy consumption per km travelled for the electric automobiles**

The radar was placed behind the automobile at a distance of 5 m. The automobile was accelerated by pressing the accelerator pedal fast, reaching a speed of 100 ± 5 km·h^{-1} (according to the speedometer). After the experimental data were recorded, the automobile returned to the start position, and the next replication was performed. The experiment involved five replications. Out of the five replications, three replications with the most coherent data were selected for the research. A curve of average values $v = f(t)$ was constructed based on the readings recorded by the computer.

The curve for the acceleration of the electric automobile is shown in Figure 5.

The experimental data showed that the acceleration intensity of the electric automobile significantly decreased. With no extra load, the maximum speed 100.09 km·h^{-1} was reached at the experimental road section in 29.86 s; with the extra load, the maximum speed of 95.74 km·h^{-1} was reached in 33.57 s.

The acceleration parameters are shown in detail in Figure 6.

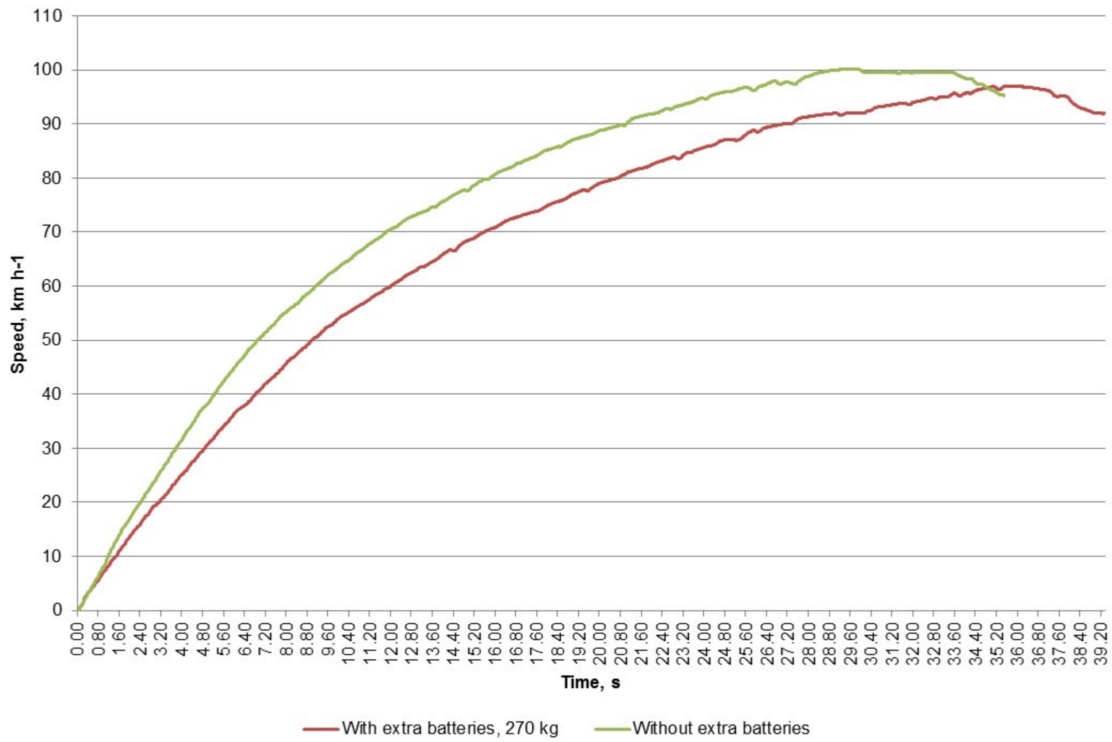

Fig. 5. **Change in the acceleration speed of the electric automobile Fiat FiorinoElectrico**

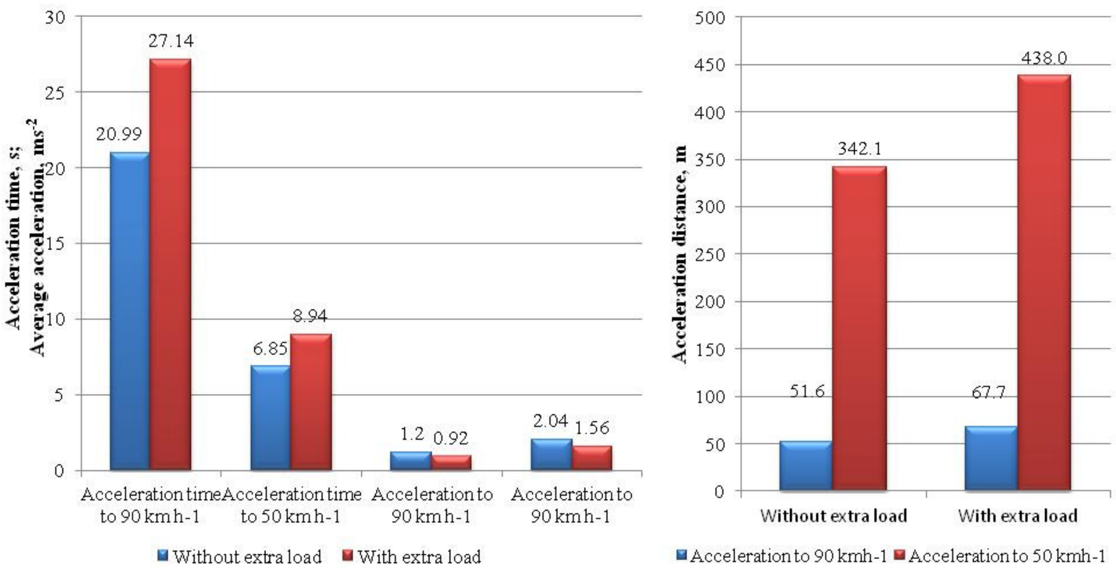

Fig. 6. **Key characteristics for the acceleration of the electric automobile**

With an extra load, the period of acceleration to 90 kmh^{-1}for the electric automobile increased by 29.3 %, while the period of acceleration to 50 kmh^{-1}was 30.5 % longer. The average acceleration to 90 km·h^{-1}and 50 km·h^{-1} decreased by 23.4 %. The distance of acceleration to 50 kmh^{-1}with an extra load of 270 kg reached 67.7 m and was 31 % longer. The automobile's acceleration to 90 kmh^{-1}with an extra load required a distance of 438 m, which was 28 % longer.

Range trials were also done on the electric automobile Fiat Fiorino Electrico with fully charged batteries both in the urban driving regime and in the non-urban driving regime in three replications. Without the extra load, the average travel range of the electric automobile was 97.01 km, while the extra load decreased the range to 89.02 km (by 8.2 %). Driving the automobile with the extra load of 270 kg reduced also the average speed from 30.69 km·h^{-1} to 29.68 km·h^{-1}.

At the next research stages, it is intended to perform an experimental examination of the dynamics and range of the electric automobile, measuring changes in the amperage and voltage of the electrical current by means of a data recorder. In this way, it is possible to determine the amount of energy consumed in dynamic micro-processes.

Conclusions

1. The weight of batteries of some models of electric automobiles can reach 25 % of the basic weight of the automobile. Extra batteries of the same technology installed on an electric automobile can increase its travel range, but decrease its dynamic and braking characteristics as well as the size of a load and the number of passengers to be transported.
2. An increase in the capacity of batteries of an electric automobile does not result in a proportional increase in the range of the automobile; therefore, more research has to be conducted to examine in detail the momentary energy consumption in order to establish this causal relationship.
3. An increase in the capacity of batteries of an electric automobile may deteriorate the acceleration parameters of the automobile, increase its operational costs, decrease the load to be transported and change its braking parameters, if using the batteries of the same technology.
4. Equipping electric automobiles with the latest generation batteries that have a lower weight and a higher capacity can considerably increase the travel range per charge.
5. Luxury class electric automobiles with a high basic weight, e.g., Tesla Model S (85), demonstrated the highest energy consumption per km travelled – 200 $Wh \cdot km^{-1}$. This parameter was, on average, two times higher than that for the compact class electric automobiles Renault Zoe and BMW I3.
6. The experiment on an electric automobile, imitating an increase in its weight by 270 kg that corresponds to the average weight of a 22 kWh battery pack, showed that the period of acceleration to 90 kmh^{-1} and 50 kmh^{-1} increased by, one average, 29.8 %. The automobile's acceleration to 90 kmh^{-1} with an extra load on an experimental road section required a 28 % longer distance.
7. With no extra load, the maximum speed reached 100.09 $km \cdot h^{-1}$; with the extra load of 270 kg, the maximum speed was equal to 95.74 kmh^{-1}.
8. With the extra load of 270 kg, the average acceleration to 90 $km \cdot h^{-1}$ decreased from 1.2 $m \cdot s^{-2}$ to 0.92 $m \cdot s^{-2}$, which was 23.4 % lower.
9. In the experiment, the electric automobile's range per charge in the urban driving regime in Jelgava decreased by 8.2 %. The average speed decreased from 30.69 $km \cdot h^{-1}$ to 29.68 $km \cdot h^{-1}$ as well.

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