INVESTIGATION OF ELECTRIC CAR ACCELERATION CHARACTERISTICS PERFORMING ON-ROAD TESTS

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Abstract. Use of electric cars have several potential benefits compared to conventional internal combustion automobiles, for example, a significant reduction of urban air pollution, less dependence on foreign oil etc. Despite these benefits, several problems limit widespread application of electric cars. Electric cars are significantly more expensive than conventional internal combustion (IC) engine vehicles due to the additional cost of their battery pack. However, battery prices are coming down and expected to drop further. Other factors deterring the adoption of electric cars are the lack of public recharging infrastructure and the driver's unfamiliarity with the electric car dynamic characteristics compared with vehicles powered by IC engines. This article deals with the electric car *Fiat Fiorino Elettrica HC-S* acceleration characteristic studies testing the car on real road. The car's acceleration intensity was determined using the scientific radar *Stalker ATS* on 1 km long road section with fully charged batteries without load, with a partially (25 – 30 %) charged batteries without load and with fully charged batteries and a 500 kg load. A time to run the car from 0 to 95 km per hour, and from 50 to 90 km per hour was measured. Speed curves according to the travelled distance were obtained. It was found that without load electric car acceleration time with 30 % charged batteries was only 1.9 – 2.5 % higher than with fully charged batteries. Loading the car, the time increases by approximately 34 %. Acceleration distance was even greater and reached 39 %.

Keywords: electric car, acceleration run, acceleration intensity, scientific radar.

Introduction

World energy resources are limited, but environmental pollution is increasing. One of the major energy consumers and polluters of environment is the road transport. According to different scenarios world energy resources may be sufficient for only next 40 to 60 years [1; 2]. Consequently, there is a need to introduce new vehicles that are environmentally friendly and consume less fossil fuel. One of such vehicle types is electro vehicle. Using of them may localize the production, utilization, and exploitation pollution, as well as it is possible to use various forms of energy:

- electricity produced from renewable resources – solar, wind, and hydro energy;
- energy derived from renewable resources by energy transfer to electricity – biogas or biofuels produced electricity in cogeneration plants;
- energy from non-renewable natural resources or environmentally harmful resources – nuclear, coal or oil energy.

Depending on the type of energy, i.e., on how the electricity is produced, electric car will be more or less environmentally friendly.

Significant electric vehicle exploitation parameter is the dynamic behaviour that allows to judge about the following features:

- electric cars fitness for road traffic, the ability to integrate into the traffic flow;
- identification of the most cost-effective driving speed to ensure maximum mileage per charge;
- ability to safely perform dynamic manoeuvres, such as the run-up and overtaking.

Materials and methods

Investigation of electric car acceleration characteristics was carried out in cooperation with the public limited company *Latvenergo AS* using their electric car *Fiat Fiorino Elettrica HC-S*.

Fiorino is conceived for build-up urban environments and small cities. It combines performance, agility and comfort with the load capacity, ease of loading and unloading, reliability and productivity of a light commercial vehicle. The car's main technical parameters [3]:

- category – M1;
- motor – asynchronous, nominal power 30 kW, maximal power (peak) 60 kW;
- brakes – energy recovery;

- recharging socket – 230 VAC – 16 A – 3 kW;
- battery – lithium up to 31.1 kWh;
- grade ability – 24 %;
- transmission – direct drive;
- maximum speed – up to 115 km·h^{-1};
- distance of run with a single full charge (range ECE 101 cycle) 100 km;
- coupe heating system with a fossil fuel.

The car's acceleration intensity was determined using the scientific radar *Stalker ATS* (See Fig. 1) on 1 km long road section.

Fig. 1. **Electric car *Fiat Fiorino Elettrica HC-S* and scientific radar *Stalker ATS***

The *Stalker Acceleration Testing System* (*STATS*) is the combination of the *Stalker ATS Professional Radar Gun* and the powerful *Stalker ATS* software program. It is a portable and accurate system for testing and analyzing vehicle performance. *STATS* provide a detailed picture of the dynamics of acceleration. It is the ultimate tool for racers and manufacturers to test and tune products for maximum performance. The *ATS* gun measures the speed of the vehicle at precise intervals, and then sends those speed samples to the computer. The *Stalker ATS* software program saves the speed data, assigns time information, and then calculates distance and acceleration rates for each data sample. This data is then saved as a file on the computer's hard drive. Since speed, time, distance and acceleration are mathematically related, having any two of these measurements means the other components can be derived with absolute accuracy.

The radar's main technical parameters [4]:

- speed range: 1 – 480 km·h^{-1};
- accuracy: ±1.069 km·h^{-1};
- target acquisition time: 0.01 s;
- maximal range for cars: 1.82 km;
- weight: 1.45 kg;
- RS-232 communication system.

Before the experiment a full battery charge was performed under laboratory conditions. Experiments were carried out on a flat and straight asphalt road surface with an average rolling resistance coefficient from 0.018 to 0.020. Road surface was dry, ambient temperature +15 ºC. Wind speed didn't exceed 2.8 $m \cdot s^{-1}$. Going to the experiment site, the car traveled 12 km.

Starting the experiment the radar was placed 5 meters behind the car. Two operators participated in the experiment. One worked with the radar, which is connected to a portable computer, the second has driven the car. Operators communicated through portable radio set. After the radar operator commands, the car driver started the car's sharp run-up, pressing the accelerator pedal all the way. Experiment was performed from 0 $km \cdot h^{-1}$ until maximum speed was achieved. After the test car returned to starting position and the next experiment repetition was carried out.

The experiment was repeated to determine the driving dynamics from 50 to 90 $km \cdot h^{-1}$. Driving started 100 – 150 meters before the radar so that crossing the radar detection area a steady speed of 50 $km \cdot h^{-1}$ was reached. After that the run-up to 90 $km \cdot h^{-1}$ was performed.

Each experiment was repeated 5 times. If during the test another car appeared on the road and disturbed the radar measurements, the experiment was repeated. From all five repetitions three were selected with the closest data, i.e., with the highest correlation between experimental series data points. Average values were calculated from at least 3 repetitions if correlation between the series data points was at least 0.995, i.e., above 99.5 %. After that curves $v = f(t)$, $s = f(t)$, $v = f(s)$ were constructed. Experiments were carried out with fully charged batteries without load, with a partially (about 25 – 30 % of maximal capacity) charged batteries without load and with fully charged batteries and a 500 kg load. The block diagram of experiments is shown in Figure 2. Electric vehicle tests were carried out in two stages, because with a single charge is not possible to provide a full cycle of the experiment and come back to the laboratory. In the first stage experiments with fully charged and partially charged batteries were performed, in the second stage – recharging batteries and loading the car with 500 kg weight, thus achieving a gross weight of the car.

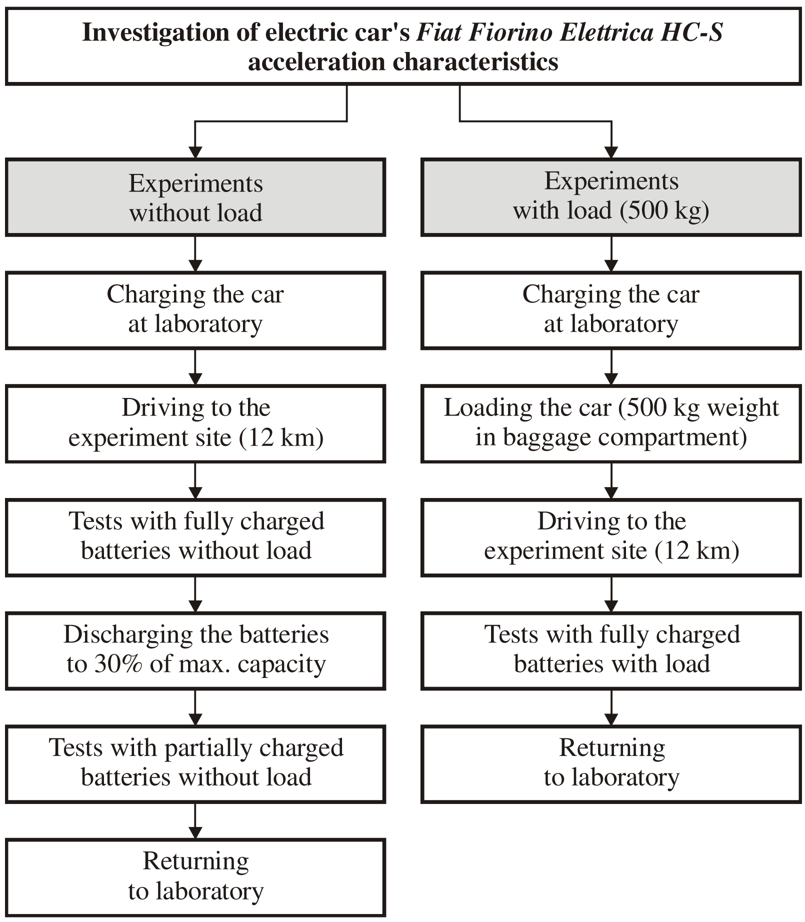

Fig. 2. **Block diagram of experiments**

Results and discussion

Acceleration characteristics, testing the car with fully charged batteries without load, are shown in Figure 3. As the maximum speed of 100 km·h^{-1} in any of the tests was not achieved, the speed 95 km·h^{-1} was chosen for comparison, which was reached also driving with the load and partially charged batteries. Data processing showed that the speed of 95 km·h^{-1} is achieved in 24.13 seconds, this time driving 421.15 meters long distance.

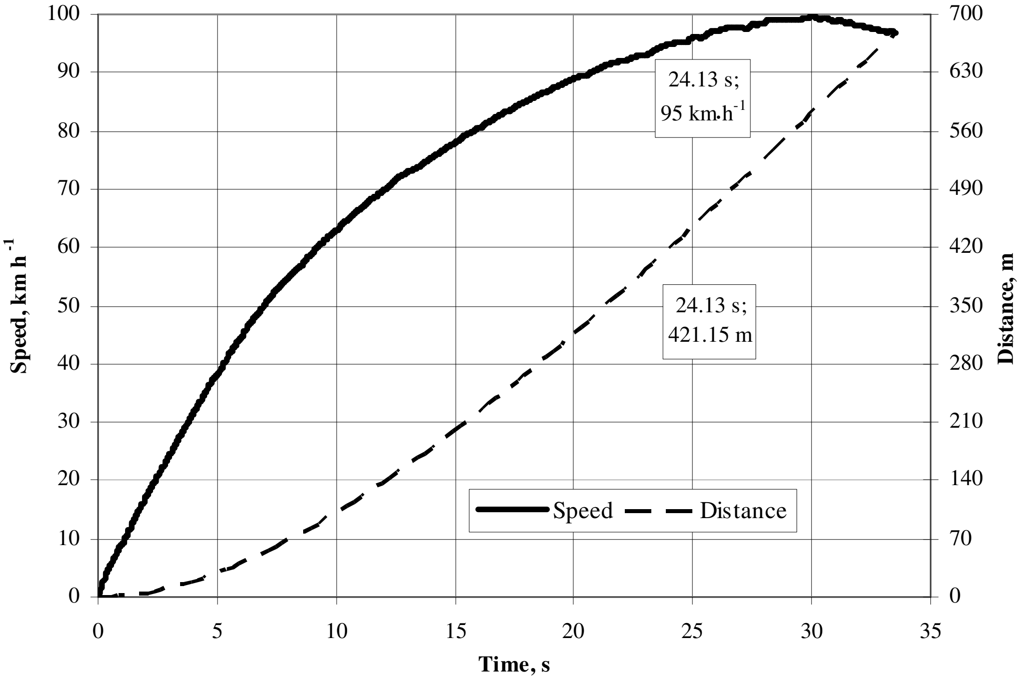

Fig. 3. **Acceleration characteristics, testing the car with fully charged batteries without load**

Figure 4 shows the acceleration characteristics, testing the car with partially (25 – 30 %) charged batteries without load. The speed of 95 km·h^{-1} is achieved in 24.58 seconds during 431.45 meters long distance.

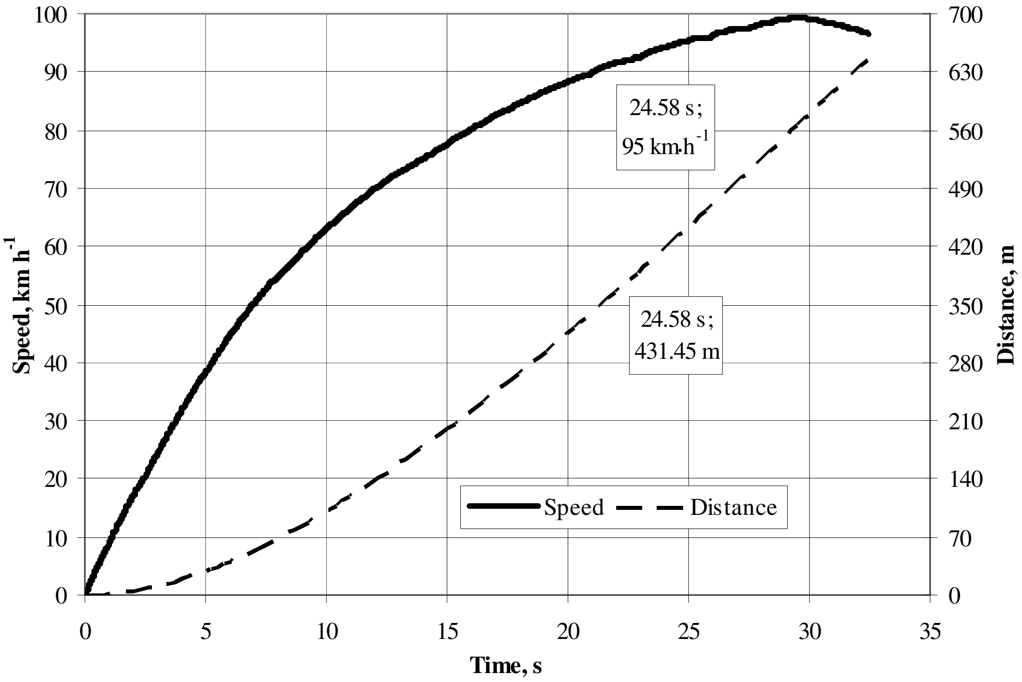

Fig. 4. **Acceleration characteristics, testing the car with partially (25 – 30 %) charged batteries without load**

Acceleration characteristics, testing the car with fully charged batteries and a 500 kg load, are shown in Figure 5. The speed of 95 km·h^{-1} is achieved in 32.90 seconds during 588.00 meters long distance.

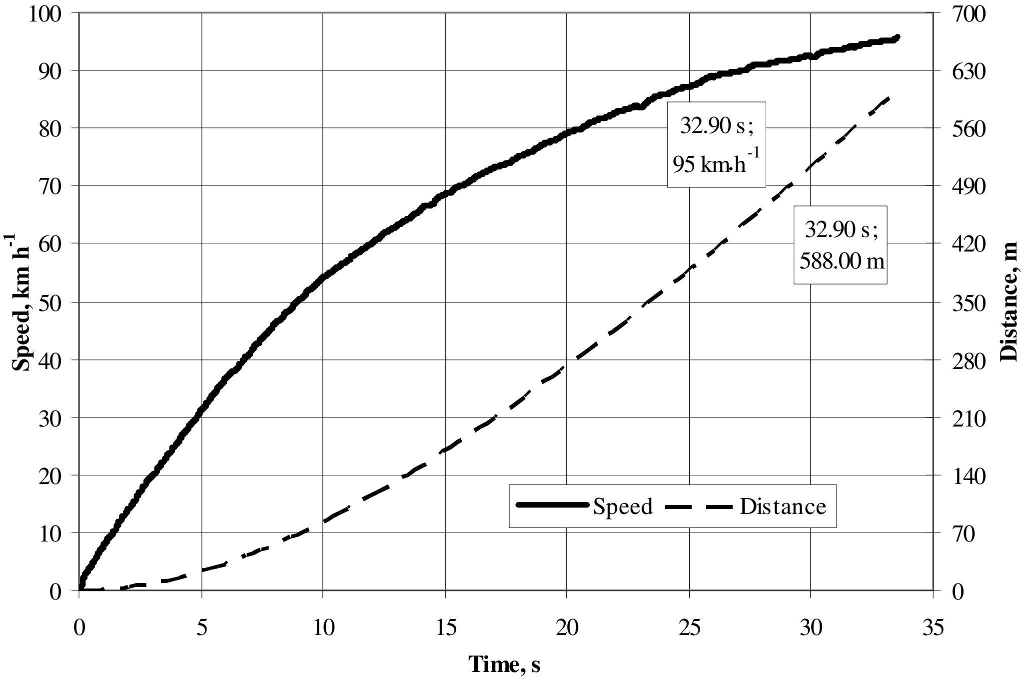

Fig. 5. **Acceleration characteristics, testing the car with fully charged batteries and a 500 kg load**

Due to the fact that the acceleration is regulated by the Electronic Control Unit of electric vehicle, the run-up (speed and distance) curves in the covering range of speeds accelerating from 0 to 95 km per hour, and from 50 to 90 km per hour are very similar and differ by less than 3 %. All the above-mentioned test mode results are summarized in Table 1.

Table 1

Summary of acceleration parameters in all test modes

No.	Test mode	Test results				
		Acceleration time from 0 to 95 km·h^{-1}, s	Acceleration distance from 0 to 95 km·h^{-1}, m	Speed at 500 m mark, km·h^{-1}	Acceleration time from 50 to 90 km·h^{-1}, s	Acceleration distance from 50 to 90 km·h^{-1}, m
1.	Fully charged batteries without load	24.13	421.15	97.67	13.86	283.95
2.	Partially (25 – 30 %) charged batteries without load	24.58	431.45	97.55	14.21	290.79
3.	Fully charged batteries and a 500 kg load	32.90	588.00	92.10	18.37	377.21

Without load and with 30 % charged batteries electric car acceleration time from 0 to 95 km·h^{-1} and from 50 to 90 km·h^{-1} was accordingly only 1.9 % and 2.5 % higher than with fully charged batteries, but acceleration distance – in average 2.4 % longer. Loading the car, the time increased by approximately 34 %. Acceleration distance was even greater and reached 39 %.

For comparison, petrol-powered *Fiat Fiorino Combi 1.4 Euro 5* (1368 cm^3, 54 kW) from 0 to 100 km·h^{-1} accelerates in 16.6 seconds, while gas-powered – in 17.5 seconds [5; 6]. Of course, in such view electric car is much less dynamic, but that comparison is not really correct, since the maximum speed for the petrol car is 155 km·h^{-1} and accelerating to 100 km·h^{-1} is far from the maximum speed, while for the electric car this speed is close to maximum. Therefore, more objective would be to make a comparison, for example, accelerating up to 80 km·h^{-1}. This was confirmed by additional experiment, in which the car *Renault Trafic 2.0 DCI* was tested. Although the car's engine is 3 times more powerful than the *Fiat Fiorino Elettrica HC-S*, *Renault* up to 80 km·h^{-1} accelerates in 14.05 seconds, but *Fiat* – in 15.72 seconds, i.e., the difference is not huge.

Conclusions

1. In experiments with a fully charged batteries without load car *Fiat Fiorino Elettrica HC-S* shows enough good dynamic performance, accelerating to 95 km·h^{-1} in 24.13 seconds, to 80 km·h^{-1} – in 15.72 seconds, and to 50 km·h^{-1} (that is important for driving in the city) – in 7.07 seconds.
2. Electric car's dynamics with partially discharged batteries is close to fully charged batteries. Acceleration time from 0 to 95 km·h^{-1} and from 50 to 90 km·h^{-1} was accordingly only 1.9 % and 2.5 % higher than with fully charged batteries.
3. Loading the car, the acceleration time increased by approximately 34 %, but acceleration distance – by 39 %.
4. Considering that the tested electric car's maximum speed is close to 100 km·h^{-1}, for comparison with the internal combustion engine vehicles it's recommended to choose a lower speed, for example, 80 km·h^{-1}, when the entire vehicle dynamics has not yet been spent.

Acknowledgements

Funding support for this research is provided by the ERAF Project "Usage of Electric Energy in Motor Vehicles of Physical Persons" (No. 2010/0305/2DP/2.1.1.1.0/10/APIA/VIAA/130). Research was carried out in co-operation with the public limited company *Latvenergo AS*.

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