# DYNAMICS OF SLOW-MOVING ELECTRIC VEHICLES

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**Abstract.** Slow-moving electric vehicles that are available in the Latvian market were ascertained. A methodology for determining the parameters of dynamics for slow-moving electric vehicles was developed. The maximum speed, acceleration time and distance were determined for various electric vehicles. An electric moped had the best acceleration characteristics among the vehicles chosen. By using the graphs of acceleration intensity, an optimum speed for the electric vehicles tested was determined to achieve their maximum distance of driving.

**Keywords:** electric energy, electric motor vehicles, electromobiles, acceleration time, acceleration, distance of driving.

## Introduction

Deposits of fossil energy are gradually running out in the world. The extensive use of fossil energy in motor vehicles pollutes the environment with such toxic substances as CO, $C_nH_m$, and $NO_x$ as well as promotes global warming due to $CO_2$ emissions. Therefore, possibilities to use other sources of energy, which are environmentally friendly, in automobiles are searched for. One of such sources of energy is electricity that can be used for cars and slow-moving motor vehicles.

The first electric vehicles have been known since the year 1830. Yet, their exploitation was limited. A more extensive use of electric vehicles was observed only in the beginning of the 20$^{th}$ century when electric taxis appeared in New York. Even in those times, electric vehicles had a few advantages compared to internal combustion engine vehicles, for instance, they did not have to be started up by spinning the engine by means of a crank, as electric starters were not available then; they were not noisy, no gases were emitted, and no fuel smell was felt. With developing the internal combustion engine designs, their use in motor vehicles sharply increased, whereas electric motor vehicles were used quite rarely. In those times, the main problem in exploiting electric vehicles was the same as today – no light, cheap, and relatively capacious battery is available that could ensure a large distance of driving, especially in non-urban traffic [1].

Every vehicle is suited for specific conditions of exploitation. Electric vehicles, irrespective of their disadvantages, can occupy a market niche and find their own use. This use can be related to the specifics of this type of vehicles – pollution localisation at the site of electric energy generation and noiseless operation.

One of the types of electric vehicles is slow-moving electric motor vehicles [2]. Slow-moving vehicles include electric bicycles and electric mopeds as well as electromobiles for shopping, golf, and tourism and other types of electromobiles, the driving speed of which does not exceed 50 $km \cdot h^{-1}$. Since such vehicles can be used in urban traffic where their dynamics can play an essential role in traffic safety, an experimental study on the dynamics of slow-moving electric motor vehicles will be conducted.

## Materials and methods

### 1. *Slow-moving electric motor vehicles and their types*

Slow-moving vehicles can be classified into two groups:

- vehicles that can take part in road traffic – electric bicycles, mopeds, single-seat electric shopping cars, and certified tourist automobiles;
- vehicles that are not certified for road traffic – golf electric cars, hearses, electric trucks for closed territories.

The engine power of four-wheel slow-moving electric motor vehicles is within a range of 1-5 kW, and their distance of driving is 40-75 km. These vehicles are usually equipped with lead deep discharge batteries. In Latvia, 10 slow-moving electric motor vehicles produced by the Melex company are presently used for tourist transportation in Sigulda and Jūrmala.

Electric bicycles are two-wheel vehicles the engine power of which is usually within a range of 0.18-0.35 kW, maximum speed of driving is 20-30 km·h$^{-1}$, and distance of driving per battery charge is 25-40 km. Lead deep discharge batteries are most frequently used for electric bicycles, but lithium-ion batteries can be also used. The engine of electric bicycles can be activated in two ways: by means of a traditional accelerator handle or at the moment of engine start-up when the driver spins pedals at certain spin rate. Electric bicycles can be quite popular, as their price is within EUR 300-700. One of the main advantages of electric bicycles is the possibility to get home by spinning pedals in a traditional way after the battery is fully discharged.

Electric mopeds are usually more powerful than electric bicycles and no pedals are available. The power of mopeds is within 1-2.5 kW, their speed of driving is up to 40 km·h$^{-1}$, and their distance of driving is up to 60 km. Due to a larger engine power, mopeds require more capacious batteries that ensure sufficient dynamic characteristics [2].

## 2. *Methodology for determining the parameters of dynamics*

Slow-moving electric motor vehicles are not intended for fast driving, yet the ability of electric motor vehicles to adapt to urban traffic can be analyzed by determining their parameters of dynamics as well as the optimum speed of driving to achieve the maximum distance of driving per battery charge can be determined according to their acceleration curves.

Before the tests are started, the air pressure required by the manufacturers was provided in the tyres of electric motor vehicles. All the electric motor vehicles were tested with fully charged batteries. The measurements of the electric motor vehicles were done on a 200 m long section of road in the suburbs of Rīga, Sigulda, and Jelgava. The road surface was asphalt in a good condition, the rolling resistance coefficient was 0.018-0.020, and the slope of the road did not exceed 1 %. The air temperature during the experiments was 15 ºC and the wind speed was 2-3 m·s$^{-1}$.

A scientific radar Stalker ATS placed on a tripod was used for the measurements. The radar measures the speed, while the other parameters – distance and acceleration – are computed. The main parameters of the radar are as follows:

- accuracy ±0.1 km·h$^{-1}$;
- speed range 1-480 km·h$^{-1}$;
- time of capturing a vehicle 0.01 s;
- weight 1.45 kg;
- operation distance up to 2500 m [3].

To conduct the research, five various electric motor vehicles were chosen – an electromobile Melex 963DS, an electric moped eGo Helio M37, an electric bicycle ER61, an electric shopping car Hawaii, and an electric shopping car City-Liner. The technical characteristics of the vehicles used in the experiments [4-7] are presented in Table 1.

Table 1 presents also the specific power of the electric motor vehicles. This indicator can characterise dynamic qualities of vehicles if the vehicle power is not too large and the adherence of wheels can ensure full use of its maximum power. The power of slow-moving electric motor vehicles is not large, therefore, it is expected that no slipping of wheels will be observed on asphalt with an adherence coefficient $\varphi$=0.7 for all the vehicles mentioned in Table 1. Larger specific power indicates larger potential acceleration dynamics. According to this parameter, the largest potential acceleration dynamics will be observed for the electric moped eGO Helio M37, while the smallest one – for the electric bicycle ER61. The correctness of these assumptions will be verified by conducting an experimental study.

*Technology of the experiments.*

Any measurement is done by experiment operators. One operator accelerates the electric motor vehicles, while the second one operates the scientific radar. The electric motor vehicles are placed in the front of the radar at a distance of 1-2 m. The height of the radar is adjusted, so that it operates at the best angle of reception.

After the start signal is given by the radar operator, the mode of filming is activated on the radar and the electric motor vehicle starts moving. The data were registered in a computer connected to the radar. Any acceleration of the electric motor vehicle is done at maximum intensity, pushing the accelerator handle to the utmost position. The acceleration is performed until stable maximum speed is achieved, keeping this speed for at least for 2-3 seconds. After the maximum speed is achieved, the radar operator stops filming and saves the data. The operator of the electric motor vehicles turns the vehicles around to drive them in an opposite direction and places them at the start position in front of the radar. In the same way, three measurements are repeated.

Table 1

**Technical characteristics of the electric motor vehicles used in the experiments**

| Technical characteristics | Model of electric motor vehicles | | | | |
|---|---|---|---|---|---|
| | Melex 963DS | eGO Helio M 37 | ER 61 | Hawaii TM4401DX | City-Liner |
| Driving distance at full charge, km | 65 | 40 | 65 | 40.23 | 35 |
| Largest driving speed, $km \cdot h^{-1}$ | 25 | 37 | 32 | 6 | 6-8 |
| Batteries | 8 units, 12 V | 2 units, 12V, 34 Ah | 4 units, 12 V, 12 Ah | 2 units, 12V, 40 Ah | 2 units, 12 V, 40 Ah |
| Voltage of electric engine, V | 48 | 24 | 48 | 24 | 24 |
| Power of electric engine, kW | 3.9 | 1.75 | 0.35 | 1.00 | 1.00 |
| Carrying capacity, kg | 450 | 114 | 115 | 159 | 150 |
| Gross weight, kg | 1135 | 173 | 150 | 255 | 245 |
| Specific power, $kW \cdot t^{-1}$ | 3.44 | 10.12 | 2.33 | 3.92 | 4.08 |
| Specific power in experiment, $kW \cdot t^{-1}$ | 5.30 | 12.50 | 2.80 | 5.12 | 5.37 |

## Results and discussion

### *3. Results of the experiments*

One of the significant indicators in vehicle dynamics is acceleration until certain speed is reached. For cars, this is the speed of 100 $km \cdot h^{-1}$, and modern street automobiles can usually reach such speed within 6-15 s. The slow-moving electric motor vehicles, which were studied, have various maximum speeds of driving that vary within 6-37 $km \cdot h^{-1}$. Due to this reason, the acceleration dynamics were compared for speeds up to 5 $km \cdot h^{-1}$ and 15 $km \cdot h^{-1}$.

Based on the research methodology, the measurements were done for the electric bicycle ER61, the electric moped eGO Helio M37, the slow-moving electromobile Melex 963DS, and the electric shopping cars Hawaii TM4401DX and City Liner. After completing the experiment, the data were processed and the average data were obtained from three measurements. Based on the measurement data, calculation was done and the result is presented in Fig.1.

The best acceleration dynamics both at a speed up to 5 $km \cdot h^{-1}$ and 15 $km \cdot h^{-1}$ was observed for the electric moped eGO Helio M37, respectively 0.49 s and 1.77 s. Since the maximum speed of the electric shopping cars does not exceed 8 $km \cdot h^{-1}$, the cars are not shown in the right side of the graph. Among the vehicles studied, the poorest result in reaching a speed of 15 $km \cdot h^{-1}$ was gained by the electric bicycle ER61. It can be explained by its relatively weak engine – only 0.35 kW. In accordance with EU legislation, the engine power of electric bicycles is limited and should not exceed 0.25 kW. The electric bicycle ER61 can also be used as a moped by operating the accelerator handle. It is possible that the engine power mentioned in normative documents may not be increased due to this reason.

The engine power of the electric motor vehicles is smaller compared to analogous internal combustion vehicles. The only exception is the electric moped, the engine power of which is approximately the same as for an internal combustion moped. Irrespective of the relatively small engine power, the electric motor vehicles showed sufficiently good dynamic characteristics owing to their excellent engine power and torque curves.

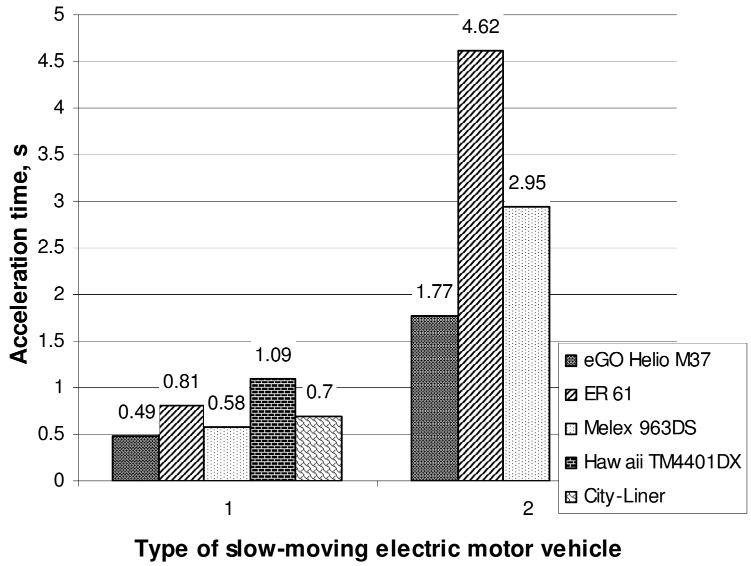


Fig. 1. **Acceleration time for slow-moving electric motor vehicles:**
1 – up to 5 km·h$^{-1}$; 2 – up to 15 km·h$^{-1}$

To compare the acceleration parameters more precisely, a graph $v=f(t)$, which is shown in Fig. 2, was constructed.

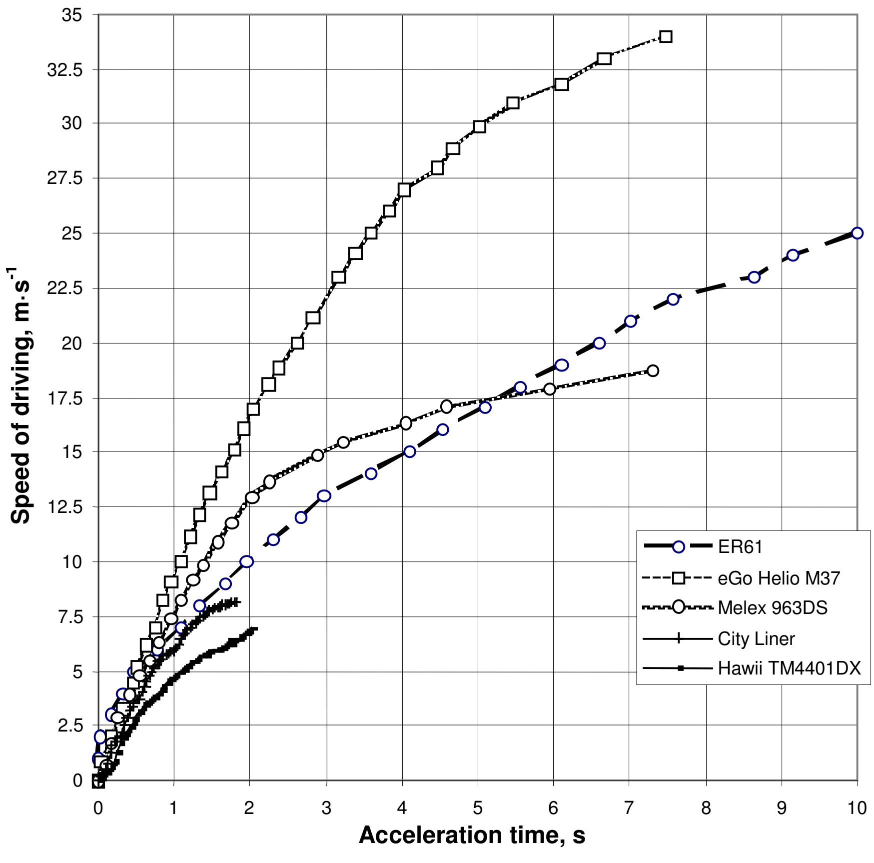


Fig. 2. **Acceleration dynamics for slow-moving electric motor vehicles**

In case if the vehicle power is not sufficient to achieve good dynamic characteristics, the speed curve is steep. At larger speeds of driving when the engine power reaches its maximum, the acceleration curve becomes flatter. As regards the electric motor vehicles studied, the curve bending point is reached at (0.7-0.8)$v_{max}$. According to provisional studies, if this speed of driving is exceeded, the engine of the electromobile is overloaded and consumes more electric energy accumulated in the battery. Therefore, the distance of driving of vehicles per battery charge decreases. Among all the electric motor vehicles, the most explicit bending point is observed for the electromobile Melex 963DS, which is reached at approximately 15 km·h$^{-1}$ or after 3 second acceleration. Further acceleration, until the maximum speed is reached, takes place very slowly.

A fact has to be noted that sometimes producers indicate larger speeds of driving for their electric motor vehicles than it is in reality. The maximum speed of driving (6 km·h$^{-1}$), which is shown in the technical characteristics, is reached only by the electric shopping cars.

As in the acceleration analysis of a speed of up to 15 km·h$^{-1}$, the fastest acceleration at the full range of speed was also observed for the electric moped eGO Helio M37. It reaches the maximum speed of driving in 7.49 seconds. Such acceleration is quite convenient for urban traffic and for merging into the flow of traffic. Given the relatively small speed of driving and the large size of it, the electromobile Melex 963DS is not well suited for urban traffic. It, according to the producer recommendations, can be better used for entertainment trips in streets without heavy traffic and outside urban areas when the nature can be enjoyed owing to the lack of engine noise.

The dynamics of the electric shopping cars is the lowest among the vehicles studied. Yet, taking into account the specifics of using these vehicles – on sidewalks, in shops, and on pedestrian crossings – the maximum acceleration is achieved in less than two seconds, which is absolutely sufficient. These vehicles can compete with pedestrians and are even faster than an average pedestrian, taking into consideration their distance of driving of up to 40 km and their maximum speed of driving that exceeds the average speed of walking of pedestrians.

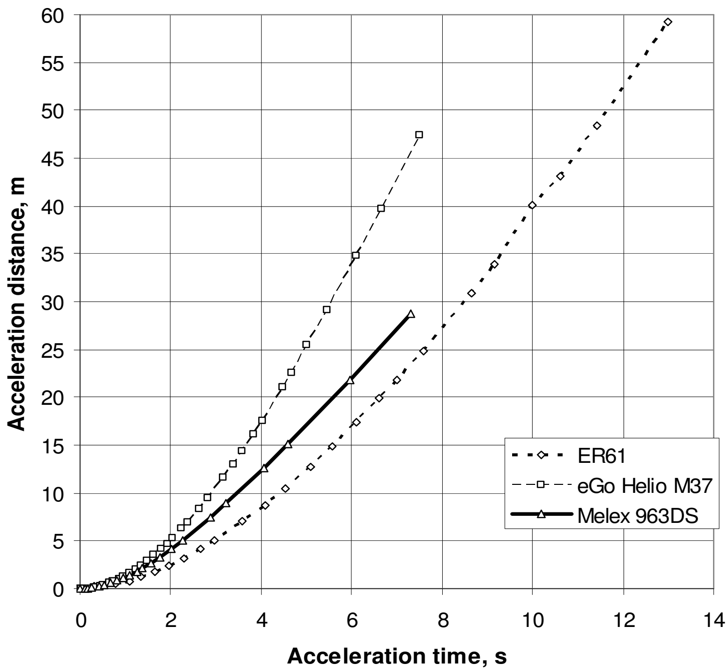


Fig. 3. **Acceleration distance for electric motor vehicles**

The acceleration distance (see Fig. 3) was analysed only for the electric motor vehicles that run faster than 10 km·h$^{-1}$. The acceleration distance for the electromobile Melex 963DS is 28.8 m, but the electric moped needs a distance of 47.39 metres to achieve its maximum speed. The largest acceleration distance or 59.28 m was observed for the electric bicycle, which can be explained by its small engine power.

## Conclusions

1. Various slow-moving vehicles are available in the Latvian market, yet their popularity is limited by the high price of these vehicles.
2. The largest specific power or 12.50 kW·t$^{-1}$ belongs to the electric moped, which ensures the highest indicators of dynamics for it – the acceleration time to reach a speed of 15 km·h$^{-1}$ is achieved in 1.77 s.

3. The longest acceleration time or 4.62 s is required for the electric bicycle ER61 to reach a speed of 15 $km \cdot h^{-1}$ due to its low specific power indicator.
4. Irrespective of the relatively small engine power, the electric motor vehicles showed sufficiently good dynamic characteristics owing to their excellent engine power and torque curves.
5. The optimum average speed of the electric motor vehicles studied is $(0.7\text{-}0.8)v_{max}$ which ensures the largest distance of driving for the electric motor vehicles.
6. In the technical characteristics, the producers of slow-moving electric motor vehicles have showed on average 10 % larger speed of driving than it was achieved in the experiments.
7. The best indicators of dynamics were observed for the electric moped eGO Helio M37; it reaches the maximum speed of driving in 7.49 seconds.
8. The dynamics of the electric shopping cars is the lowest among the vehicles studied, yet, given the specifics of using these vehicles, the maximum acceleration is achieved in less than two seconds, which is sufficient.

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