INVESTIGATION OF DYNAMICAL AND EXPLOITATION PARAMETERS OF SLOW MOVING ELECTRIC CAR ON CHASSIS DYNAMOMETER

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Abstract. Because of extinction of fossil fuels and increasing pollution of atmosphere scientists and authorities are more and more searching for how to decrease the dependency on fossil fuels. As known, fossil fuels make hazardous emissions. One of the ways how to decrease the impact on environment is to make more efficient internal combustion engines (less consumption; less emission). Another way is to establish alternative fuels (biofuels) or alternative drive (electric drive) of vehicles. A number of regulations have been worked out to increase the specific weight of alternative fuels of total consumption in transport. Electric energy in commercial vehicles is used already for a long time (trolleys, trams, trains) but exploitation of electric vehicles as transport of physical persons is coming more and more topical during the recent years. Electric motor vehicles are more expensive than conventional internal combustion engine vehicles due to the costs of batteries. Expenses of batteries are decreasing and recharging infrastructure is progressing. If amortization costs are ignored then direct driving costs with electric motor vehicle are frequently lower in comparison with internal combustion engine vehicles. The article deals with the low-speed electric motor vehicle *Melex 963DS* dynamical and experimental parameter studies on the power stand *Mustang MD1750*. The dynamical parameters - power, torque, acceleration time and acceleration distance up to 30 $km \cdot h^{-1}$ were determined. The exploitation parameters to determine are autonomy, driving time, charging time and charging energy. All parameters, except spin-up curves, were determined with different load regimes and with fully charged batteries. The maximum obtained electric motor power is 5.02 kW at 1858 rpm and maximum achieved torque is 34.54 N·m at 1132 rpm. Acceleration time and distance changes with a load and is from 102 to 155 seconds and from 666 to 1146 meters without load and with 150 % load. The results show that load has no considerable impact on the exploitation parameters of the vehicle driving it on power stand and the difference in autonomy driving the vehicle without load in comparison with overload of 150 % is only 2.623 km, difference in driving time is 00:01:20 h, difference in charging time 00:00:40 h and difference in charging energy 0.03 kWh.

Keywords: slow-moving electric motor vehicle, acceleration time, acceleration distance, charging energy, charging time, driving time, power curve, torque curve, chassis dynamometer.

Introduction

Emission standards for vehicles in many countries are based upon the *United Nations Economic Commission for Europe* (UN ECE) standards commonly referred as *Euro* standard. Current emission standards in the EU countries are referred to as *Euro1* up to *Euro5*, whereas *Euro5* comprises the strictest emission standard. Internal combustion engine vehicles produce such hazardous gases as nitrogen oxides (NO_x), carbon oxides (CO, CO_2), hydrocarbons (HC), charcoal fumes, smuts, sulfur dioxide (SO_2), benzene and lead. In Fig. 1 Euro limits for diesel fuelled commercial vehicles are described, whereas *Euro5* comprises the strictest emission standard [1]. The *Euro6* standard is worked out and it is planned that this standard will become effective in September, 2014.

One of the ways to decrease air pollution by transport is to make more stringent desires anent on emission standards (evolution *Euro1* to *Euro5*, *Euro6*), that makes engine manufacturers to work out more and more effective and environment friendly engines. But, as known, each new product requests for investments and permanent research. The second way to decrease air pollution by direct operation of transport is to exploit electric motor vehicles.

As the electric motor vehicles during direct exploitation make no hazardous emissions (exhaust gases) exploitation of them is one of the alternatives to decrease air pollution in urban areas (cities, agglomerations). Besides that, electric motor vehicles make no noise that is important, for example, in crossings, parking-places, residential areas etc.

The above mentioned reasons to exploit electric motor vehicles are connected with direct impact on humans. Another reason to exploit them is connected with resources of fossil fuels.

At present the combustion of coal, natural gas and crude oil gives about 90 % of the total amount of energy consumption. Calculations have shown that resources of coal will be enough for 250 years, crude oil for 40 years and natural gas for 65 years. The next lack of fossil fuels (coal, peat, petroleum products, natural gas etc.) is hazardous emissions [2].

Depending on the way how the energy is obtained, electric transport is more or less environmentally friendly, especially in urban areas (trams, trolleys, trains, buses, taxi, operative transport, trip transport and private transport), and makes no hazards, such as emissions and noise made by internal combustion engines.

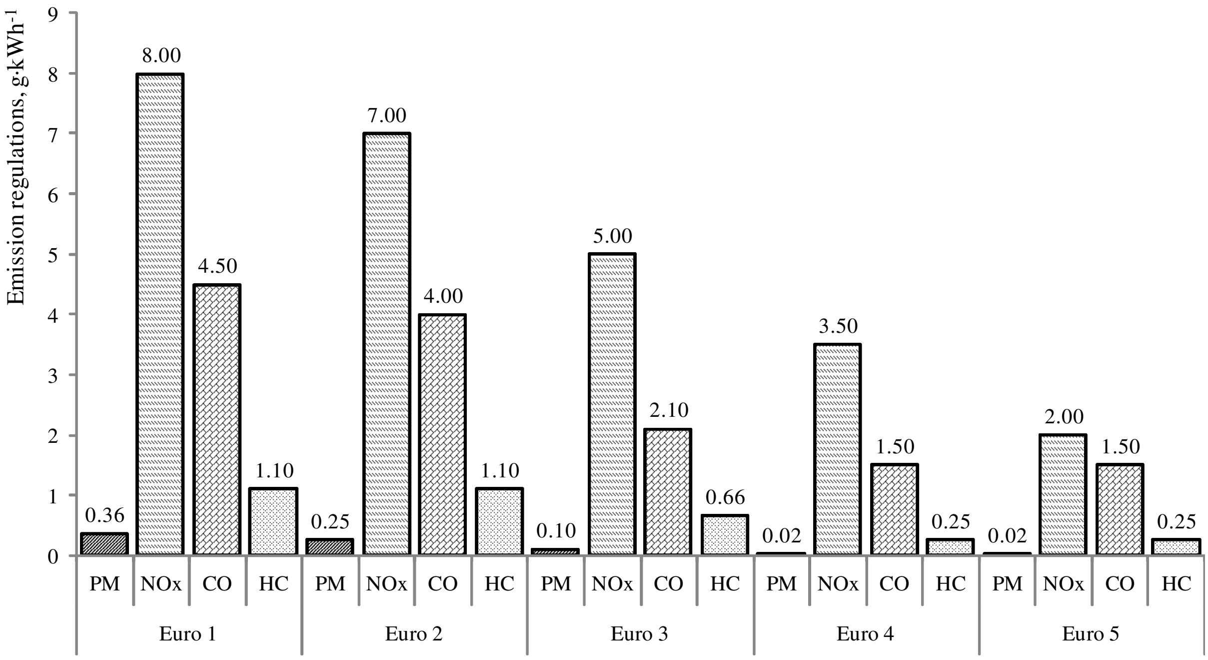

Fig. 1. **Past and current emission legislation broken down to more relevant emission categories:** PM – particulate matter; NO_x – nitrogen oxides; CO – carbon monoxides; HC – hydrocarbon

Electricity as a transport fuel could [3]:

- decrease the oil dependence, as electricity is a widely-available energy vector that is produced from several primary energy carriers;
- improve the energy efficiency through higher efficiency of an electric drive train;
- decrease the CO2 emissions of the transport sector along with the expected continuing increase in the share of renewable energy sources in the EU power generation mix, supported by emission capping through the EU Emission Trading Scheme;
- provide for innovative vehicle solutions requiring less resources and allowing better vehicle utility optimisation.

Significant electric motor vehicle exploitation parameters are the dynamic behaviour and exploitation parameters.

Materials and methods

The experimental research was made on a slow–moving electric motor vehicle *Melex 963DS*.

Slow-moving electric motor vehicles can be classified into two groups [4]:

- 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.

In Latvia, 10 slow–moving electric motor vehicles produced by the Melex Company are presently used for tourist transportation in Riga, Sigulda and Jurmala and are certified for road traffic. The slow moving electric motor vehicle *Melex 963DS* main technical parameters are [5]:

- category – L7e;
- motor – asynchronous, maximal power 3.9 kW at 3200 rpm, 48 V, SepEx;
- weight/gross weight – 762/1212 kg;

- specific power – 3.22 kW·t^{-1};
- brakes – hydraulic, energy recovery up to 5 %;
- recharging socket – 230 VAC; 16 A;
- battery – heavy duty deep cycle lead acid up to 31.1 kWh;
- transmission – direct drive;
- maximum speed – up to 32 km·h^{-1};
- distance of run with a single full charge – up to 65 km;

Investigation of slow moving electric motor vehicle dynamical and exploitation characteristics was carried out on the Chassis Dynamometer *Mustang MD-1750* at the *Scientific Laboratory of Biofuels* of the Motor Vehicle Institute of the Faculty of Engineering (Jelgava, P.Lejina Street 2).

Mustang MD-1750 is a stationary chassis dynamometer that allows to perform tests of technical diagnosis of light ground motor vehicles with single axis drive. The power stand is equipped with the necessary additional tools to determine the engine speed as well as after rotation speed of rollers the actual driving speed of the vehicle and overdriven distance are determined. In parallel with the above mentioned parameters a line of other parameters can be registered, for example, ambient temperature, air relative humidity and air pressure, engine power and torque, acceleration intensity etc. [6].

Fig. 2. **Slow–moving electric motor vehicle *Melex 963DS* on power stand.**

The stand management is provided by MD 7000 management platform. On the stand it is possible to perform the following tests: power test, constant load test, constant power stand, constant speed tests, manual load test, road simulation tests, acceleration test, emission test, quarter mile test etc.

The chassis dynamometer *Mustang MD1750* main technical parameters are as follows [6; 7]:

- speed range: 1 – 360 km·h^{-1};
- maximum power: 1286 kW (1750 HP);
- maximum absorption power: 294 kW (400 HP);
- rated accuracy of the load cell: ± 0.1 %;
- maxium load on rollers: 4540 kg;
- diameter of rollers: 1.27 m;
- width of rollers: 0.7112 m;
- air requirements: 5.5 bar.
- power requirements: 230 V; 60 Hz; 40 A.

Before the experiments a full battery charge was performed under laboratory conditions. The roller surface was dry; temperature in the laboratory was +17 to +18 ºC.

The slow-moving electric motor vehicle *Melex 963DS* tests were carried out in a number of stages that could be divided into two groups: dynamical and exploitation parameters. If the first parameters could be established with a single charge of batteries, then the exploitation parameters take a lot of time, because with fully charged batteries one measurement could be taken and batteries have to be recharged. The experiment duration occurs till the driving speed drops down by the speed of 5 km·h^{-1}.

Dynamical parameters

The experiment was repeated to determine the driving dynamics from 0 to 30 km·h^{-1}, i.e., acceleration time from 0 to 30 km·h^{-1} (seconds) and acceleration distance from 0 to 30 km·h^{-1} (meters) in the following load regimes: without load, with 50 % load, with 100 % load and with 150 % of load.

Exploitation parameters

The exploitation parameters to determine are autonomy with fully charged batteries (km), driving time (hours), charging time (hours) and charging energy (kWh). These parameters were determined in the following load and speed regimes: maximal starting speed (fully pressed accelerator pedal) without load, with 50 %, 100 % and 150 % load and with starting speed 20 km·h^{-1} (partially pressed accelerator pedal) with 100 % load. The last regime was selected to determine if there is some impact of the driving speed on autonomy.

Load regimes

The experiments were carried out with the following load regimes:

- without load (762 kg);
- 50 % of load (987 kg);
- 100 % of load (1212 kg);
- 150 % of load (1437 kg);

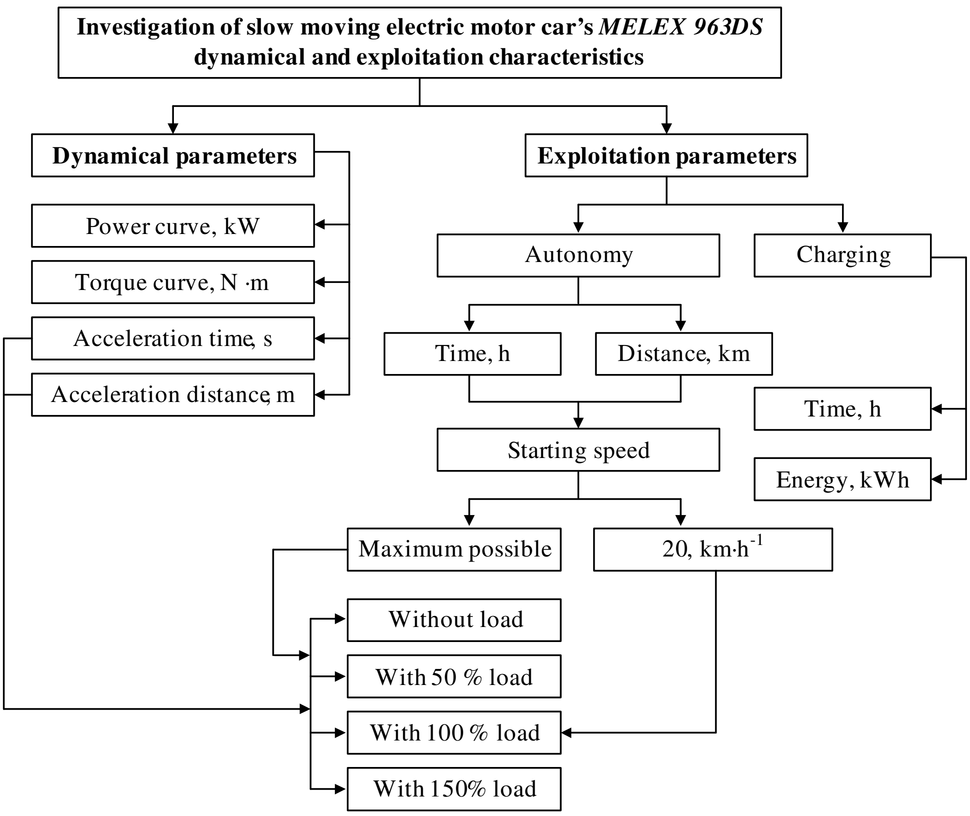

Fig. 3. **Block diagram of experiments**

According to literature [8], each measurement was repeated 3 times ($\alpha = 0.95$; $p = 0.05$; $t = \pm 3\sigma$). If some of the measurements are too originate, they were repeated one more time. After that electric motor spin-up curves and acceleration columns were constructed. The block diagram of the experiments is shown in Figure 3.

Results and discussion

In the first stage the dynamical parameters of the low-moving electric motor vehicle were determined. As seen from Fig. 4, the maximum power of the slow-moving electric motor vehicle is 5.02 kW at engine speed 1858 rpm. Because of the specific character of the power stand it is not possible to determine the maximum torque of the electric motor. As known, electric motors expand their maximum torque already from small revs, but because of power stand delay, it is determined only from 1000 rpm and the maximum obtained torque registered by the power stand were 34.54 N·m at 1132 rpm.

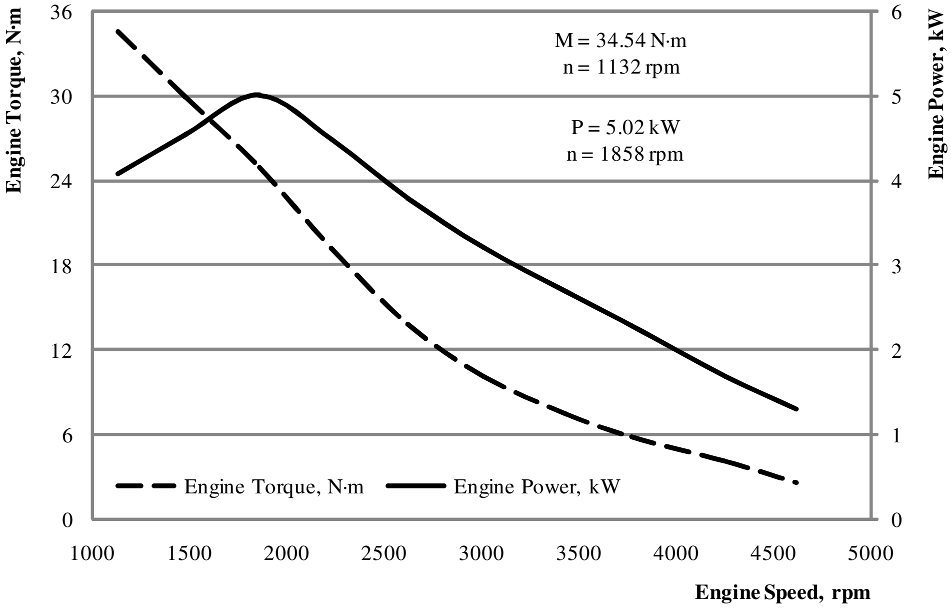

Fig. 4. **Electric motor spin-up curves**

Figure 5 shows the acceleration dynamics testing the slow-moving electric motor vehicle with four load regimes. As seen from Figure 4, the speed 30 km·h^{-1} without load is attained in 102 ± 3 seconds, with 50 % load in 117 ± 10 seconds, with 100 % load in 133 ± 9 seconds and with 150 % load in 152 ± 19 seconds.

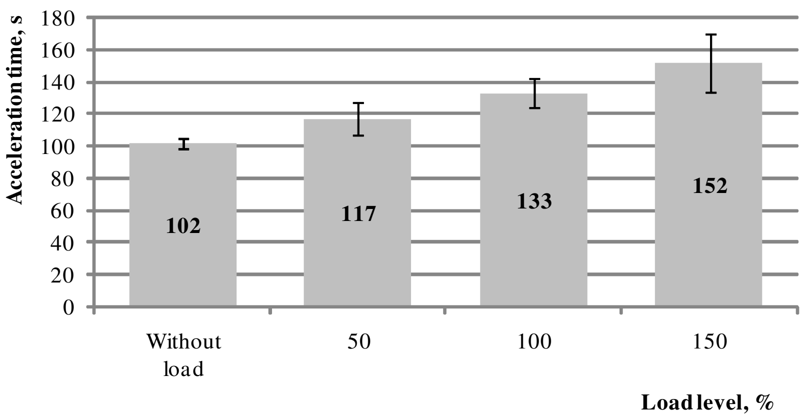

Fig. 5. **Acceleration time up to 30 km·h^{-1} speed**

Figure 6 shows the acceleration distance during the speed 30 km·h^{-1} is attained. From Figure 6 it is seen that the speed 30 km·h^{-1} without load is attained during 666 ± 29 m, with 50 % load during 794 ± 24 m, with 100 % load during 922 ± 45 m and with 150 % load during 1146 ± 49 m.

In Figures 5 and 6 there are also error bars depicted that, according to Gauss (normal) distribution, characterize ± 3 standard errors.

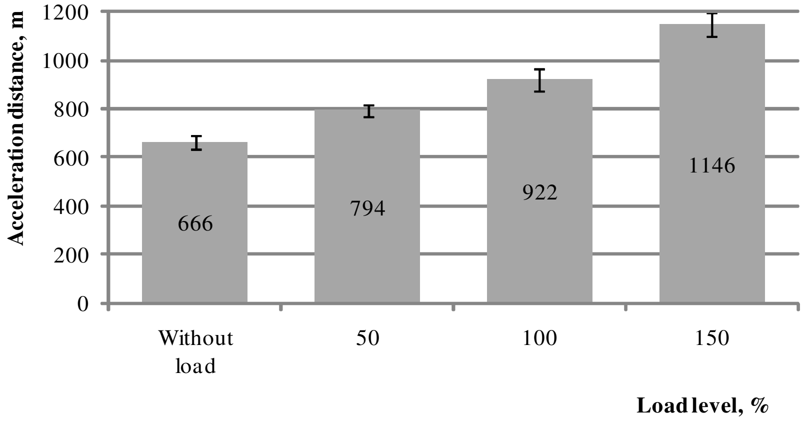

Fig. 5. **Acceleration distance up to 30 km·h^{-1} speed**

During determination of the exploitation parameters of the slow-moving electric motor vehicle intraday one drive was performed. The results are summarized in Table 1.

Table 1

Summary of exploitation parameters

Load level	Distance, km	Driving time, h	Charging time, h	Charging energy, kWh
Without load	47.820 ± 0.085	2:12:00 ± 0:04:35	7:44:40 ± 0:20:53	9.09 ± 0.47
50 %	46.859 ± 0.475	2:02:40 ± 0:14:00	7:34:00 ± 0:17:35	7.67 ± 0.63
100 %	45.364 ± 0.095	2:02:40 ± 0:02:00	7:37:00 ± 0:18:05	8.68 ± 0.36
100 %, v_o = 20 km·h^{-1}	50.071 ± 2.147	3:10:40 ± 0:15:43	8:39:00 ± 0:22:31	9.50 ± 0.51
150 %	45.197 ± 0.781	2:10:40 ± 0:03:36	7:44:00 ± 0:18:44	9.06 ± 0.28

As seen from Table 1, the exploitation parameters do not differ much depending on the load regime. If we compare the exploitation parameters of the low-speed electric motor vehicle operating with extreme load regimes (without load and with 150 % load), it is seen that the difference of autonomy is 2.623 km (2.09 %), of driving time 00:01:20 h (1.01 %), of charging time 00:00:40 h (0.14 %) and of charging energy 0.03 kWh (1.33 %). These results stimulate to suppose, that on the power stand load does not have so big influence on autonomy than on the road because of the specific driving regime on the road (crossing, pedestrian crossings, traffic lights, wind etc. conditions) that allows changing the driving speed.

In order to clarify what impact on the exploitation parameters the starting speed has, several drives were carried out with different starting speeds. If in general research the exploitation parameters were determined with maximum possible speed and different loads, than for comparison the starting speed was selected 20 km·h^{-1} and load 100 %. As it is seen the reduction of the starting speed of drive to 20 km·h^{-1} allows to increase autonomy for 4.707 km (9.40 %), but wherewith the driving time increases of 1:08:00 h (35.66 %), charging time of 1:02:00 h (11.95 %) and charging energy of 0.82 kWh (8.63 %) in average.

Conclusions

1. The maximum power of the slow-moving electric motor vehicle is 5.02 kW at 1858 rpm and maximum achieved torque is 34.54 N·m at 1132 rpm. Having regard of the power stand delay the achieved torque could not be considered as veritable.
2. The acceleration time up to 30 km·h-1 depending on the load varies from 102 ± 3 seconds (without load) to 152 ± 19 seconds (150 % load).
3. The acceleration distance up to 30 km·h-1 depending on the load varies from 666 ± 29 m (without load) to 1146 ± 49 m (150 % load).
4. The driving distance till full discharge of batteries varies from 45.197 ± 0.781 km (150 % load) to 47.820 ± 0.085 km (without load).
5. The driving time till full discharge of batteries practically does not depend on the load and is within 2:02:40 to 2:12:00 hours.
6. The charging time also does not depend on the load and is within 7:34:00 to 7:44:40 hours.

7. The charging energy depending on the load varies from 7.67 (50 % load) to 9.09 (without load) kWh.
8. Decreasing the maximum starting driving speed to 20 km·h-1, the driving distance increases for 4.707 km (9.40 %), driving time for 1:08:00 h (35.66 %), charging time of 1:02:00 h (11.95 %) and charging energy of 0.82 kWh (8.63 %) in average in comparison with the same data when the starting speed is selected as the maximum possible.

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