Bench tests results of the traction parameters of the light two-wheeled electric vehicle

B Kolator  S Racewicz  and  A Olszewski
University of Warmia and Mazury in Olsztyn
ul. Michała Oczapowskiego 2, 10-719 Olsztyn, Poland

Corresponding author: bronislaw.kolator@uwm.edu.pl

Abstract. The article presents methodology for testing the traction parameters of the lightweight two-wheeled electric vehicle on the laboratory stand and in road conditions. The tests have been carried out using MAHA LPS 3000 chassis dynamometer and the supplementary instrumentation designed and made for this purpose. The values of the drive torque and the peripheral speed of the drive wheel have been acquired using the dynamometer's measurement and registration equipment. At the same time the electric parameters of the electric motor have been measured. In order to simulate the road conditions drive on the chassis dynamometer, the set of parameters has been adjusted using measurements carried out in the real road conditions. For this purpose, during the quasi-dynamic passage of the vehicle at the constant linear speed, on the horizontal road surface and in the ambient conditions similar to those in the dynamometer laboratory the current and the voltage transmitted to the electric motor have been measured. Determining the electric power demand of the vehicle in the aforementioned conditions has enabled to adjust the chassis dynamometer parameters in order to proceed with the laboratory tests in the road conditions simulation mode.

1. Introduction
The use of the electric drive in the wheeled vehicles is dictated by, among others, environmental and operational requirements. Electric bicycles can be used for various purposes, for example as a vehicle for police or law enforcement authorities in cities where parking and traffic are problems. In this article, the term electric bicycle is used to describe a light two-wheeled vehicle with electric drive.

Electric bicycles are gaining more and more popularity around the world, especially in China, Europe, Japan, Taiwan and the United States. The annual global motorcycle market is currently around 80 million units a year, almost all of them are based on the combustion engine. The predicted increase in the demand for an electric bicycle can double the size of the two-wheel market. The report predicts that the largest category will be electric bicycles with 56% of the electric market on two wheels, then motorcycles with 43% drive and e-scooters on the distant third place with less than 1% [6].

Directive 2002/24/EC of the European Parliament and the Council of 18 March 2002 announced the principle of categorization, describing a hybrid-driven bicycle, also known as Electric Pedal Cycles, or simply pedelecs and mopeds. A typical battery for e-bikes requires exactly or about 8 hours to a full charge, and this power is enough to transfer the e-bike at a distance of 48 to 60 km with an average speed of about 20 km/h [5].
Research shows that electric cars are too expensive to compete with internal combustion vehicles (ICE). Electrification via the electric two-wheeled technology (ETW) may be an option, especially in urban regions. Nevertheless, few studies have been carried out on the ETW in the EU [7].

The design and construction process of this type of vehicles are undertaken by many scientists and engineers. The electric vehicle market is mainly focused on automotive constructions as they can be used throughout the entire calendar year. Issues related to the electric bikes can be solved by using specially designed drives that are the most efficient in a specific type of operation. These include city bikes, mountain bikes, distance bikes and fast bikes [2, 3].

Wilhelm, et al. presented a method of finding parameters characteristic for an e-motorcycle which are based on real data and using them to simulate the energy consumption of a vehicle in a standard test cycle. The purpose of this method is to simplify and reduce the costs of standard tests required to measure the energy consumption of electric motorcycles before selling them on the Swiss market. Finally, it turned out that these methods effectively enable the use of simulation models trained in the real driving conditions to run the required standard test cycles instead of the costly dynamometric tests in order to estimate the energy consumption [8].

In the theoretical details of the electric bikes Upadhya et al. introduced detailed information on the components used in e-bikes, their performance, their importance in terms of efficiency in terms of energy consumption and energy transmission (engine capacity), performance (types of components and functions) and other technical aspects [9].

Somchaiwong and Ponglangka in their article presented a control of regenerative power for an electric bike by generating a model situation of the regenerative energy [4].

On the basis of the operational tests Łebkowski [1] stated that the use of the electric drive system in the motorcycle reduces harmful emission as well as energy consumption (approx. 35 Wh/km) in comparison to the combustion engine motorcycle (approx. 635 Wh/km). Moreover, it significantly reduces noise, especially during starting and accelerating.

2. Test method and measuring equipment

As a test object, a light two-wheeled electric vehicle has been chosen. It has been powered by a brushless DC motor of 3 kW mounted in the rear wheel hub. Brushless Direct Current (BLDC) motor is a type of synchronous motor, where magnetic fields generated by both stator and rotor rotate with the same frequency (Fig. 1). The battery used in the vehicle has been built of 220 SONY US18650VTC5 C5 2600mAh cells in a configuration of 20 in series and 11 in parallel, which gives a maximum voltage of 84 V and a capacity of 27.5 Ah. The battery management system (BMS) is a device that automatically supervises the process of charging and discharging the battery. Vehicle travel speed Has been controlled by the Sabvoton SVMC072080 controller. The display with percentage charging degree has been used to check the battery level.

![Mechanical structure of the BLDC motor](image-url)
The drive wheel has had a diameter of 26 inches and has been equipped with BIG BUDDY Deli 4.0 tire. The maximum speed of the vehicle has been about 80 km/h. The weight of the vehicle ready to ride is 76 kg plus the cyclist about 75 kg what gives the pressure on the drive wheel of about 886 N. Figure 2 shows the vehicle prepared for the laboratory tests. An electric vehicle that has been built does not meet the conditions of an electric bike or electric moped according to the law of the European Union [5].

![Figure 2. The vehicle prepared for the laboratory tests](image)

Light electric vehicle research has been performed on the MAHA LPS 3000 chassis dynamometer which has been supplied by the Vehicle Dynamic Testing Laboratory of the University of Warmia and Mazury in Olsztyn. This dynamometer provides an exact simulation of the predefined road load conditions. Used dynamometer allows applying the load to the vehicle drive system as a function of the vehicle speed which reflects different driving conditions. The dynamometer software has many operating modes that allow, in addition to the classic vehicle's engine performance tests, to examine the efficiency of the drive systems, as well as to control the speed of the vehicle. Chassis dynamometer is equipped with a microprocessor-controlled computing unit for graphic and digital display of the measurement results.

During the tests it has been assumed that the vehicle is moving linearly on the flat surface of the road with an incline of 0% (horizontal). The total driving force $F$ on the rear wheel is determined by the relation (1), and the power $P$ on the wheel is described by equation (2):

$$F = F_r + F_w + F_g + F_b = m \cdot g \cdot f + 0,5 \cdot \rho \cdot C_D \cdot A_f \cdot v^2 + m \cdot g \cdot w + m \cdot a$$

$$P = F \cdot v$$

where $v$ is the speed of the vehicle, $a$ is the acceleration of the vehicle, $m = 123$ kg is the mass of the vehicle, $g = 9,8$ m s$^{-2}$ is the gravity acceleration, $f = 0,009$ is the rolling resistance coefficient, $\rho = 1,2$ kg m$^{-3}$ is the air density, $C_D = 0,5$ is the air drag coefficient, $A_f = 0,62$ m$^2$ is the frontal area, $w$ is the road with an incline.

After determining the individual components of the driving force, one has to enter the appropriate vehicle coefficients and data into the computer program of the dynamometer. The power coefficients
of the individual forces should be calculated at a reference speed of 25 m/s. The driving simulation takes place in a generator and motor manner according to the developed model (Fig. 3).

Figure 3. MAHA dynamometer monitor view for driving resistance simulation

In order to determine the engine speed characteristics of the vehicle the operating mode “Discrete Power Measurement” has been used. Using discrete power measurement it is possible, depending on the speed or rotational speed, to reach the defined points and temporarily hold them. These points should be determined before starting the measurement (Fig. 4). The start and the end speed or rotational speed as well as the step and the holding time should be defined by the controlling person.
In this chassis dynamometer mode the characteristic of the drive shaft torque is determined as a function of the wheel rotational predefined speeds or as a function of vehicle speed. On this basis, the power characteristic of the engine is determined as a function of the rotational speed or the vehicle speed.

3. Test results
After preparing the vehicle for testing on the dynamometer, the measurements during road condition driving simulation (Fig. 5) of a light electric vehicle in the range from 0 km/h to max speed have been performed. Sample waveforms of recorded values have been shown in Fig. 6.
Figure 6. Measured values of the MAHA test bench during drive simulation of the vehicle

According to the dynamometer parameters, the mass of the vehicle during the tests should be greater than 200 kg. Unfortunately, this condition has not been met. As a result, the traction force has been dependent on the grip force. The torque on the vehicle wheel has significantly exceeded the traction force and the inertia moment of the eddy current brake. Accordingly, the wheel slip on the dynamometer rollers has made it impossible to achieve the maximum accelerations of the vehicle. In the 14th second at the speed of 25 km/h (Fig. 6) the maximum acceleration has been equal to 1.29 m/s², the traction force has been equal to 29 N and the power has been equal to 1.98 kW. During this test the maximum values of the force and the power have been respectively equal to 42.9 N and 2.1 kW.

Fig. 7 and Table 1 present examples of the registered vehicle traction parameters during energy tests of the electric motor. The time intervals correspond to three ways of driving simulation: from 0 to 30 seconds – acceleration, from 30 to 130 seconds – driving at a constant speed of about 62 km/h, from 140 to 155 seconds – braking with energy recovery. Indexes “RA” and “HA” signify that the measurements have been performed using rear measuring roller of the dynamometer.
Figure 7. Measured values of the MAHA test bench during drive simulation of the vehicle.
Table 1. Parameters values of the electric motor during tests on the chassis dynamometer

| Measurement date: 08.01.2018 (11:34) |
|--------------------------------------|

| Time [s] | n [rpm] | v [RA [m/min]] | P [kW] | a [m/s²] | F [HA [N]] | Distance counter [km] |
|----------|---------|----------------|--------|----------|-----------|-----------------------|
| 0,000    | 0       | 0.00           | 0.00   | 0.00     | -6.4      | 9.236                 |
| 5,000    | 65      | 8.71           | 0.26   | 0.469    | 16.3      | 9.240                 |
| 10,000   | 146     | 19.59          | 0.84   | 0.609    | 26.3      | 9.259                 |
| 15,000   | 273     | 36.58          | 2.58   | 1.045    | 33.4      | 9.295                 |
| 20,000   | 399     | 53.44          | 3.35   | 0.834    | 36.2      | 9.356                 |
| 25,000   | 444     | 59.58          | 1.61   | 0.244    | 40.3      | 9.433                 |
| 30,000   | 457     | 61.24          | 0.95   | 0.067    | 39.8      | 9.516                 |
| 35,000   | 458     | 61.59          | 0.72   | 0.014    | 38.8      | 9.600                 |
| 40,000   | 461     | 61.75          | 0.68   | 0.010    | 37.2      | 9.684                 |
| 45,000   | 462     | 61.91          | 0.66   | 0.009    | 36.1      | 9.769                 |
| 50,000   | 462     | 61.94          | 0.62   | 0.001    | 36.0      | 9.854                 |
| 55,000   | 463     | 62.01          | 0.65   | 0.009    | 35.6      | 9.938                 |
| 60,000   | 463     | 62.03          | 0.63   | 0.003    | 35.6      | 10.023                |
| 65,000   | 463     | 62.04          | 0.62   | 0.001    | 35.6      | 10.108                |
| 70,000   | 463     | 62.09          | 0.62   | 0.004    | 35.3      | 10.163                |
| 75,000   | 464     | 62.14          | 0.62   | 0.004    | 34.8      | 10.278                |
| 80,000   | 463     | 62.10          | 0.60   | 0.000    | 34.8      | 10.363                |
| 85,000   | 464     | 62.19          | 0.60   | 0.003    | 34.2      | 10.448                |
| 90,000   | 464     | 62.21          | 0.58   | -0.002   | 34.1      | 10.534                |
| 95,000   | 464     | 62.14          | 0.57   | -0.005   | 34.2      | 10.619                |
| 100,000  | 464     | 62.20          | 0.59   | -0.001   | 34.1      | 10.704                |
| 105,000  | 463     | 62.13          | 0.57   | -0.004   | 33.9      | 10.786                |
| 110,000  | 463     | 62.11          | 0.59   | -0.002   | 33.8      | 10.874                |
| 115,000  | 464     | 62.19          | 0.58   | -0.001   | 33.5      | 10.959                |
| 120,000  | 464     | 62.10          | 0.57   | -0.001   | 33.4      | 11.044                |
| 125,000  | 463     | 62.08          | 0.57   | -0.001   | 33.3      | 11.129                |
| 130,000  | 463     | 62.12          | 0.56   | -0.003   | 33.2      | 11.214                |
| 135,000  | 451     | 60.50          | 0.34   | -0.041   | 32.9      | 11.299                |
| 140,000  | 322     | 43.23          | -2.48  | -0.947   | 47.1      | 11.372                |
| 145,000  | 201     | 26.96          | -1.53  | -0.895   | 44.4      | 11.421                |
| 150,000  | 86      | 11.48          | -0.72  | -0.859   | 42.2      | 11.448                |
| 155,000  | 0       | 0.00           | -0.02  | -0.086   | 7.4       | 11.454                |
| 160,000  | 0       | 0.00           | 0.00   | 0.000    | 4.0       | 11.454                |

In order to eliminate the influence of the vehicle acceleration on the measured parameters of the electric motor the discrete power measurement has been applied. Sample waveforms of the recorded values have been presented in Table 2 and in Figure 8.
Table 2. Parameters values of the electric motor during tests on the chassis dynamometer

| n [rpm] | v [km/h] | P [kW] | M [Nm] |
|---------|----------|--------|--------|
| 114     | 15,3     | 1,1    | 89,4   |
| 148     | 19,8     | 1,8    | 117,4  |
| 186     | 24,9     | 2,6    | 132,2  |
| 223     | 29,9     | 2,9    | 124,1  |
| 260     | 34,9     | 3,1    | 113,6  |
| 298     | 39,9     | 3,3    | 104,8  |
| 335     | 44,9     | 3,4    | 96,5   |
| 372     | 49,9     | 3,7    | 93,7   |

Figure 8. Characteristics of power and torque of the electric motor as a function of driving speed

4. Conclusion

Basing on the test results obtained on the chassis dynamometer MAHA LPS 3000 one has to note that in a limited range the light two-wheeled electric vehicles can be tested. The article presents the
methodology for testing this type of vehicles. Discrete power measurement on the dynamometer is suitable to achieve the speed characteristics of the electric motor.

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