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Development and validation of model of the electric car energy consumption

Streszczenie. *W pracy przedstawiono propozycję nowego modelu zużycia energii przez samochód elektryczny, wyznaczanego na podstawie przebiegu prędkości. Model został zweryfikowany przez porównanie z wynikami uzyskanymi na hamowni podwoziowej w warunkach opisanych w europejskim cyklu miejskim. Uzyskano dobrą zgodność zarówno chwilowego, jak i całkowitego zużycia energii elektrycznej w trakcie jazdy. Opracowany model może zostać wykorzystany do analizy rozmieszczenia stacji ładowania, które umożliwią szybkie ładowanie lub wymianę akumulatorów trakcyjnych w celu zwiększenia zasięgu samochodów elektrycznych.* (***Nowy model zużycia energii przez samochód elektryczny, bazujący na podstawie przebiegu prędkości****)*

Abstract*. This paper presents the proposed new model of energy consumption by electric car, determined based on the course of the velocity. The model has been verified by comparing with the results obtained on a chassis dynamometer under the conditions described in the New European Driving Cycle (NEDC). A good compliance with both momentary and total electrical energy consumption while driving was obtained. The model can be used to analyze the distribution of charging stations locations that will allow quick charging or replacement of traction batteries to extend the range of electric cars.*

Słowa kluczowe: samochód elektryczny, zużycie energii, akumulatory trakcyjne, hamownia podwoziowa
Keywords: electric car, energy consumption, traction batteries, chassis dynamometer

Introduction

Introduction to general use of the fleet of electric cars [1] (FEV - Full Electric Vehicle) requires knowledge of the energy consumption by the vehicles, as well as information on their daily runs and characteristics of the routes covered. This makes it possible to design optimal capacity of the traction batteries [2] and the parameters of the drive system in order to ensure the widest possible group of potential users of such a vehicle. The feature desired by customers is the greatest possible capacity battery, which allows to maximize the range of the car, however, increase of the amount of electricity stored accumulators an increase in the mass of the battery pack. Mass of lithium-ion cells is about 10 kg/kWh [2]. Typical traction battery pack mass of the electric cars sold by carmakers is between 200 kg to 300 kg. The increase in vehicle mass adversely affects its traction, energy consumption and crash safety [3]. In order to secure the battery pack at the moment of collision, special energy-absorbing and securing structures made of modern high-strength steels are used [4-6]. Reducing vehicle mass by reducing the size of the energy storage results in restricting the range in the common solutions at the moment, to about 150 km, so that the scope of its use is limited to specific cases: commuting to work, school, shopping or service selected public services tasks. At the end of a driving cycle car is connected to a source of electricity to charge the batteries. It is usually done at night and lasts several hours. Extending the daily runs for the car with electric motor requires one of two solutions: fast charging or replacing the battery pack [7-10]. In both cases, it is essential to optimally plan the network of charging stations that will allow free movement of the vehicles in a given area. To analyze the distribution of elements of a system enabling the energy supply to the accumulators the knowledge required is of the actual real conditions of the use of electric cars. Since the percentage of such vehicles, even in countries with great emphasis put on ecological transport, is low, and not all vehicles are equipped with the appropriate recorders, it is very difficult to design an optimum charging system.

One way to solve this problem is to use existing tachometric data collected for the combustion-powered vehicles by, i.a. companies managing fleets of cars. Unfortunately, these databases contain only basic information about the position and speed of the vehicle or the average fuel consumption per time unit. It is difficult to accurately estimate, on those bases, the power consumption by the vehicle. This paper proposes a model of estimating the energy consumed by an electric vehicle, based on which it is possible to estimate the instantaneous power consumption from the traction batteries, using the course of the velocity. The model was validated by comparing the results of testing the electric car on a chassis dynamometer, obtained under laboratory conditions.

Standardized test of the energy consumption, on a chassis dynamometer

Electrical energy consumption tests have been carried out on the Zilent Courant electric car [11, 12]. Basic technical parameters of the vehicle are presented in Table 1.

Table 1. Technical parameters of the electric car used in tests

Dimensions (length x width x height)	3615 x 1563 x 1533 mm
Mass of vehicle in running order (without batteries)	831 kg
Mass of vehicle in running order	1170 kg
Maximum speed	85 km/h
Traction motor	Asynchronous 120V, type GLMI15A0
Continuous motor power	8.5 kW
Instantaneous power	17 kW
Traction Batteries	120V/100 Ah
Gearbox	Manual, five-gears

Analysis of energy consumption during the New European Driving Cycle was carried out on a AVL-Zoellner chassis dynamometer. During the test the following parameters were recorded at a frequency of 1 Hz:

- velocity based on signal from a chassis dynamometer)
- the traction battery voltage
- amperage of the current drawn from the energy storage.

Detailed information concerning filtering and signal processing of the experimental data may be found in the references [11, 12]

The theoretical course of the velocity used during tests [13, 14] consists of four elementary urban cycles lasting 195 s. Each cycle comprises: idle - 60 s, the acceleration - 42 s, constant speed - 59 s; braking – 34 s.

The graph showing theoretical and measured velocity as the function of time is shown in Figure 1. The observed discrepancies between the courses reflect the need to manually control the speed of the vehicle during the test and the test car's technical capabilities.

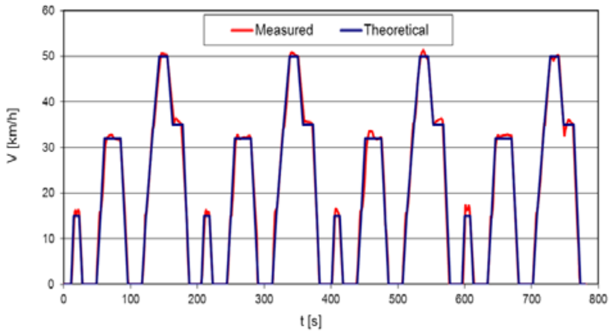

Fig. 1. Course of the velocity in the urban test measuring energy consumption in accordance with the Regulation 101 UN ECE

Proposed model to evaluate the electric car's energy consumption

In the simplest terms, the energy required to power the vehicle E_{TOT} can be expressed as the sum of three components: the energy needed to overcome the total resistance E_O; constant energy consumed by the vehicle E_{const} and energy needed to change the kinetic energy of the vehicle $E_{\Delta k}$:

(1) $$E_{TOT}(V) = E_O(V) + E_{const} + E_{\Delta k}(\Delta V)$$

The energy of the total resistance was determined by recording the vehicle speed V while coast-down from 80 km/h. The relationship obtained as an average of 10 measurements was approximated using polynomial:

(2) $$E_O(V) = 0{,}2869V^2 + 5{,}12V - 169{,}6$$

Comparison of the measured and calculated values of power of total resistance is shown in Figure 2.

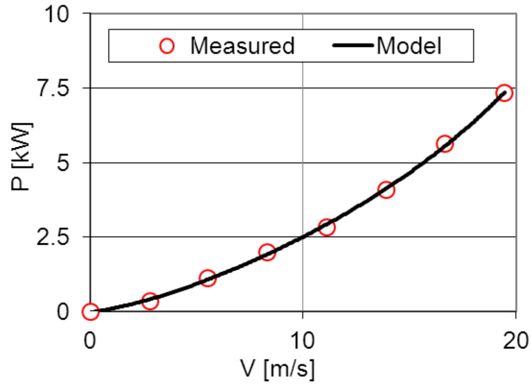

Fig. 2. The power of total resistance as measured and calculated by the equation (2)

While driving electric car as well as when it is stationary, there is a necessity for the operation of some sub-systems such as e.g. motor controller, power assisted brakes and power steering, dashboard instruments. Therefore, the traction battery is supplying a certain constant power independently of the speed. Based on the measurements, its value was determined as E_{const} = 0,23 kWh. The assumption of a constant energy consumed by the electric vehicle subsystems from the traction batteries concerns specific technical solution used in the test vehicle. In other cases, power can be drawn from additional batteries, which must be taken into account in the calculations.

To increase the speed of the vehicle, it is necessary to provide a certain energy which corresponds to a change in the value of the kinetic energy of the car. As a result of losses in energy conversion systems η_E and mechanical components η_M only a part of the energy consumed from the battery is converted into kinetic energy of the vehicle. In addition, it is necessary to take into account the fact, that during acceleration of the vehicle some part of the energy is required to spin up the rotating elements located in the drive train η_{SPIN} [15]. The efficiency of the drive system can be described as:

(3) $$\eta_{TOT} = \eta_E \eta_M \eta_{SPIN}$$

Based on previous publications [9], the adopted overall efficiency of the drive system was 50%.

Figure 3 presents the power drawn from the traction batteries, calculated based on the proposed model and measured during the electric car test on a chassis dynamometer. Power has been determined during Urban Driving Cycle (UDC) by means of a recording system, which allowed the measurement and recording of the velocity as well as voltage and current on the traction batteries. The graph shows some peaks in time corresponding to the acceleration of the vehicle, resulting from a gear shift.

The largest differences with values of about 3 kW are short-term peaks. They occur mainly during acceleration when shifting gears. The reason for differences may be minimal differences in the synchronisation of recording the data by the recorder (current, voltage) and the dynamometer (speed) or the model imperfection. However, since the duration of the peak is very short (a few seconds) they have no significant effect on the calculated energy value used by the vehicle during the test.

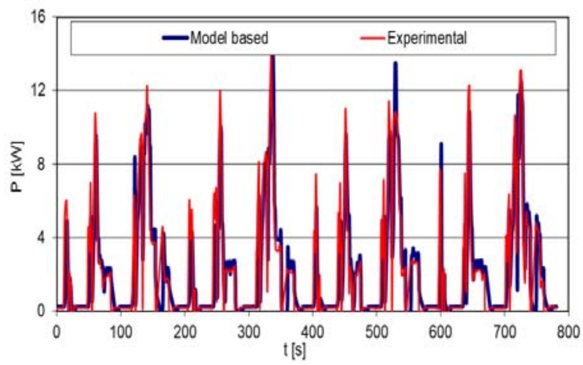

Fig. 3. Power consumed from the traction batteries, calculated and measured on a chassis dynamometer using the recording system prepared

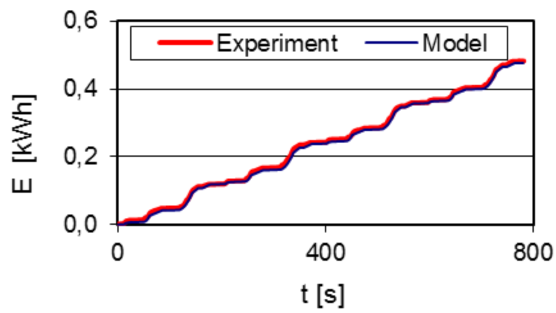

Fig. 4. The energy extracted from the traction batteries during the urban cycle, measured and calculated based on the proposed model

Comparison of the calculated and measured energy consumed by the vehicle during the reference tests using European Urban Driving Cycle, is shown in Figure 4. Energy value calculated based on the model was 0,476 kWh while the one measured using a chassis dynamometer was 0,464 kWh. The difference between the obtained results is therefore less than 3%.

Summary

The model developed of the electric car energy consumption, takes into account the energy required to change the vehicle velocity, constant power consumption by on-board equipment and the energy of the total resistance. The difference between the energy consumption by a car in a standard urban cycle, calculated and determined during verification tests on a chassis dynamometer, was less than 3%. Thus, the relationship developed can be used to analyze the vehicle's electric power demand, in which the only variable input is a course of the velocity.

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