Abstract: The maintenance of modern means of transport requires an assessment of energy consumption. This paper presents a methodology for testing electric wheelchair. The analysis of vehicle movement and the knowledge of forces affecting the vehicle are necessary to determine the components of energy balance, such as kinetic energy, energy of rolling resistance and losses in the power transmission system. The study was conducted for three different driving cycles. The motion parameters for each of the driving cycles were analyzed. The control electronics in electric wheelchair drives converts the commands of the driver: direction, accelerator, brake pedal position, into the corresponding control commands input to the power semiconductors, while at the same time observing specified limits: current, voltage, motor speed. The paper describes a research method for testing a wheelchair equipped with electric engine. The tests were conducted for specified operating conditions involving the following constrained motion on a horizontal road section. The effect of selected operating parameters on the work of the electric drive system was investigated. The paper also gives examples of the results of the conducted road tests of the wheelchair. The object of the tests was the electric wheelchair. The vehicle is suitable for transporting people weighing 80 kg. Two electric engines powered by batteries with the voltage of 24 V were used for driving the vehicle.

Keywords: energy consumption, electric vehicle, wheelchair, energy balance, electric propulsion

1. INTRODUCTION

Seeking opportunities to save energy in road transport has led to some research into new concepts of vehicle drives. An important problem in such studies is the choice of the right power transmission system and technical parameters as well as obtaining favourable performance properties, so that the future vehicle ensures maximum energy savings and at the same time certain environmental benefits. The above conditions are fulfilled, inter alia, by vehicles equipped with electric power transmission systems [1, 5, 6, 7].

The basic power transmission system of the electric vehicle consists of the source of electric energy, an electric machine and mechanical devices which transfer energy to the
drive wheels of the vehicle. The most common source of electric energy is the electrochemical battery, which stores energy necessary for the movement of the vehicle.

The electric machine acts as a transmitter of electric energy into mechanical energy. Mechanical energy is transmitted to the drive wheels mainly through mechanical transmissions with constant or variable ratio. Designers seek to eliminate mechanical gears and develop systems with a larger number of electric engines directly coupled to the drive wheels.

One of the most important parameters of the electric vehicle is its range. Electric vehicles have a small range due to the limited capacity of batteries. It is problematic to increase such capacity mainly because of the weight and dimensions of the battery. Increasing the range of electric vehicles is the most important constructional problem [2, 3, 4].

Vehicle movement is the consequence of the driving force that performs work on a given section of the road by balancing resistance and overcoming inertia forces. This work corresponds to energy expenditure necessary for the realization of car movement according to the velocity profile, represented by function courses $v(t)$.

Energy consumption is the ratio of energy put into the scheduled work to the effect of this work. Depending on the type of energy which is provided, energy consumption can be direct or cumulative. Thus, the unit of energy consumption is the quotient of the energy unit and the unit of work effect. To make it possible to specify the values of energy consumption, the type of energy which is provided or cumulated should be determined.

Energy consumption of the movement is the basic component of energy balance. This value varies within a wide range depending on the speed profile which is realized. As a component of energy balance, it has a decisive influence on the total energy consumption in motion with variable speed.

Energy consumption of movement $E$ is the sum of energies used to overcome particular components of resistance to motion which appear in equation (1):

\[
E = E_t + E_p + E_k + E_w
\]  

(1)

where:
- $E_t$ - energy used to overcome rolling resistance,
- $E_p$ - energy used to overcome air resistance,
- $E_k$ - kinetic energy or its increase,
- $E_w$ - energy used to overcome the hill.

Taking into consideration the equivalence of work and energy, each component of equation (1) can be determined by means of appropriate dependences:

- energy used to overcome rolling resistance

\[
E_t = \int_0^{S_n} F_t ds
\]  

(2)

where: $F_t$ – force of rolling resistance, $S_n$ – distance

- energy used to overcome air resistance

\[
E_p = \int_0^{S_n} F_p ds
\]  

(3)
where: \( F_p \) – force of air resistance, \( S_n \) – distance
- kinetic energy or its increase

\[
E_k = \int_{0}^{S_n} F_k \, ds
\]  
(4)

where: \( F_k \) – resultant force, \( S_n \) – distance

\[
E_k = \frac{mv^2}{2}
\]  
(5)

where: \( m \) – mass, \( v \) - speed
- energy used to overcome the hill

\[
E_w = \int_{0}^{S_n} F_w \, ds
\]  
(6)

where: \( F_w \) – forces of overcome the hill, \( S_n \) – distance.

The components of energy consumption of motion from equation (1) can be also expressed as a function of time. In certain cases it is advantageous since the values of these components largely depend on the velocity profile which is realized [12-15].

Equation (1) refers to any case of movement. In the case of a wheelchair at its maximum speed, the force of air resistance \( F_p \) is very small and therefore this force is not taken into consideration. The vehicle in question moves on the flat terrain in the course of its work. The adopted model of the wheelchair is characterized by the following parameters: max. speed 8 km / h, range 30-45 km, total weight 80 kg.

Together with the increase in the speed of steady movement \( v \), the mean of movement speed intended for acceleration and deceleration of the vehicle also increases.

During the acceleration of the vehicle, kinetic energy increases. In such a vehicle as a wheelchair, no systems making it possible to recover energy while braking are applied. Due to the high cost of necessary equipment and a small value of the vehicle maximum speed \( V_{\text{max}} \approx 8 \) km / h, it is economically unprofitable. Therefore, ultimately, vehicle kinetic energy is mostly dissipated in the braking system. The important parameters are the time of acceleration and achieved acceleration. They mainly affect the kinetic energy of the vehicle. The analysis of vehicle movement and the knowledge of forces affecting the vehicle are necessary to determine the components of energy balance, such as: kinetic energy, energy of rolling resistance and losses in the power transmission system. For the user of the vehicle, only the part of the energy stored in the battery and ready to be used is important.

All the components of energy \( E \) ready to be used are directly or indirectly dependent on the parameters of the vehicle movement. Energy consumption of movement is defined as a portion of energy associated with movement.

The energy of the wheelchair depends on the mean speed in the driving cycle and the capacity of the battery which is used. Many factors influence energy consumption. The impact of the factors, which are the most important from the point of view of the purpose of work, on the properties of the vehicle was analysed in the paper. One group includes
factors related to the operation of the vehicle, the second group are factors connected with the design of the vehicle.

The maximum speed value which the wheelchair can obtain is limited by the fact that it is necessary to ensure safety of the people who will use it and also those who will be close to the route of the wheelchair. The speed of the wheelchair does not exceed 10km / h. In the case of movement on the curvilinear path, its value is much lower. This limitation stems from the need to ensure stable cornering.

The increase in maximum speed value obtained in linear motion results, in any case, in the increase in energy consumption for a given route segment, but might not necessarily contribute to the shortening of travel time and its increase on a given route segment.

2. EXPERIMENTAL TESTS OF THE WHEELCHAIR

The object of the tests was the wheelchair. The vehicle is suitable for transporting people weighing 80 kg. Two electric engines powered by batteries with the voltage of 24 V were used for driving the vehicle. The rated power of the engine at the speed of 8 km / h is 230W. The engines are designed for continuous operation. The rated current of the engine \( I_n = 10 \) A. Two acid-lead Varta batteries with starting current 390 A (EN) and the capacity of 42Ah connected in series were used as the source of energy.

A set consisting of a portable Notebook computer and a measurement card Velleman PSC10 were used for recording data from the measurements. The unit was connected to the LM 258 system (the measurement of voltage on the shunt), the LM 2907N-8 system (the measurement of speed - inductive sensor mounted on the drive wheel and the measurement of voltage on the engines) (Figure 1, Figure 2).

![Fig. 1. Diagram of the system for measuring current, voltage and speed](image-url)
During the tests, the courses of measured values were recorded. In order to adjust the signals to the measurement card, preliminary measurements were carried out and the ranges of particular measurement tracks were determined.

After the preliminary tests had been carried out, the following courses were recorded: of current $I$, speed $V$, voltage $U$ on driving motors (Fig. 3, Fig. 4, Fig. 5). The measurement results from 9 attempts for a horizontal road section were recorded in appropriate measurement files. The tests were conducted at three different speeds and at three different loadings. Processing the recorded measurements in order to compare the impact of particular factors was necessary to determine energy consumption. The paper presents the results of calculations for the following cases:

- Courses of kinetic energy $E_k$ for loading with mass $m_1$ (70 kg) for the speed of running in the first, third and fifth gear (Fig. 6),
- Courses of kinetic energy $E_k$ for the speed of the first gear at loading with mass $m_1$ (70 kg), $m_2$ (80 kg), $m_3$ (90 kg) (Fig. 7),
- Courses of electric energy consumption $E_e$ for loading with mass $m_1$ (70 kg) for the speed of running in the first, third and fifth gear (Fig. 8),
- Courses of electric energy consumption $E_e$ for the speed of the first gear at loading with mass $m_1$ (70 kg), $m_2$ (80 kg), $m_3$ (90 kg) (Fig. 9),
- Courses of kinetic energy and electric energy consumption for loading with mass $m_1$ (70 kg) for the speed of the first gear (Fig. 10).
Fig. 3. The course of values recorded in the measurement file for loading with mass $m_1$ (70 kg) and the speed of running in the first gear.

Fig. 4. The course of values recorded in the measurement file for loading with mass $m_1$ (70 kg) and the speed of running in the third gear.
Fig. 5. The course of values recorded in the measurement file for loading with mass $m_1$ (70 kg) and the speed of running in the fifth gear.

Fig. 6. Graph showing the course of $E_k$ for $m_1$ (70 kg) at speeds for the first, third and fifth gear.
Fig. 7. Graph showing the course of $E_k$ for the speed of the first gear at three loads

Fig. 8. Graph showing the course of $E_e$ for $m_1$ (70 kg) at speeds for the first, third and fifth gear
Fig. 9. Graph showing the course of $E_e$ for the speed of the first gear at three loads

Fig. 10. Graph showing the course of $E_k$ and $E_e$ for $m_1$ (70 kg) for the speed of the first gear
3. SUMMARY

The study shows that there is a significant impact of the set maximum speed on current $I$ drawn by the engine. When the vehicle is starting, a sharp increase in current consumption occurs, and then there is an intensive decline. The decrease in the supply voltage occurring in the initial time range is the result of a sharp increase in current consumption associated with the voltage drop on the internal resistance of the battery.

When the wheelchair is supplied by 2 batteries with the voltage of $U = 24$ V, maximum current reaches the value of 47 A.

The demands for electric and mechanical energy in particular gears at various masses are similar for low driving speeds.

The obtained results make it possible to select speed in order to reduce energy consumption while driving and to increase the range.

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