PARAMETERS CALCULATION OF TRACTION MOTOR AND BATTERY PACK FOR ELECTRIC VEHICLE APPLICATION

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Introduction. According to [1], 91% of the world population live in places where the Air Quality Index (AQI) exceeds World Health Organization limits. The transport industry is one of the biggest sources of air pollution, especially in big cities, because of internal combustion engine usage. Electric vehicles can be a solution to this problem as they cause no harmful emissions. Moreover, the electric drivetrain is more efficient, cheaper to run, and maintain.

While designing an electric vehicle propulsion system, it is crucial to select an appropriate traction motor and battery pack. These parts of the powertrain have a huge impact on vehicle performance, especially on energy efficiency, power/weight ratio, and power reserve.

Purpose of the article is to present the method of calculating the parameters of traction motor and battery pack for electric vehicle drivetrain, based on a conventional automobile with internal combustion engine.

Material and results of the research. It was decided to take Mini Countryman 1.5 MT One as the basis car, as this compact vehicle is perfect for city usage. The main parameters of the selected car are the following [2]: vehicle mass $m = 1440 kg$, vehicle frontal area $S = 1.83 m^2$, rolling resistance coefficient $f = 0.01$, aerodynamic drag coefficient $C_x = 0.32$, wheel radius $r = 0.3 m$, reduction gear ratio $i = 2$. Firstly, desired performance characteristics of the automobile should be defined. Let us consider vehicle acceleration speed from 0 to 100 *km/h* equal to 10*s* and top speed equal to 140 *km/h*.

Then, vehicle acceleration is given by:

$$a = \frac{100 km/h}{10s} = \frac{27.8 m/s}{10s} = 2.78 \left(\frac{m}{s^2}\right). \tag{1}$$

Maximum wheel angular speed is defined by:

$$v_{\max} = \omega_w \cdot r_w, \tag{2}$$

$$\omega_w = \frac{v_{\max}}{r_w} = \frac{140 km/h}{0.3m} = \frac{38.9 m/s}{0.3m} = 121.9 \left(\frac{rad}{s}\right), \tag{3}$$

where $v_{\max}$ is the vehicle's top speed, ω_w is the wheel angular velocity, r_w is the radius of the wheel. Converting *rad/s* into *rpm*, we obtain:

$$n_w = \omega_w \cdot \frac{30}{\pi} = 121.9 rad/s \cdot \frac{30}{\pi} = 1164.6\ (rpm), \qquad (4)$$

where n_w is the wheel angular velocity in *rpm*.

The power reserve of the electric vehicle is taken equal to 160 km, as it is enough for city usage in Ukraine. For further calculations, it is considered that the driving cycle is equal to 40 km, representing 25% of vehicle power reserve. The selected driving cycle simulates the vehicle movement, consisting of frequent start/stops and two regions of acceleration from zero to top speed. It is shown in Fig. 1.

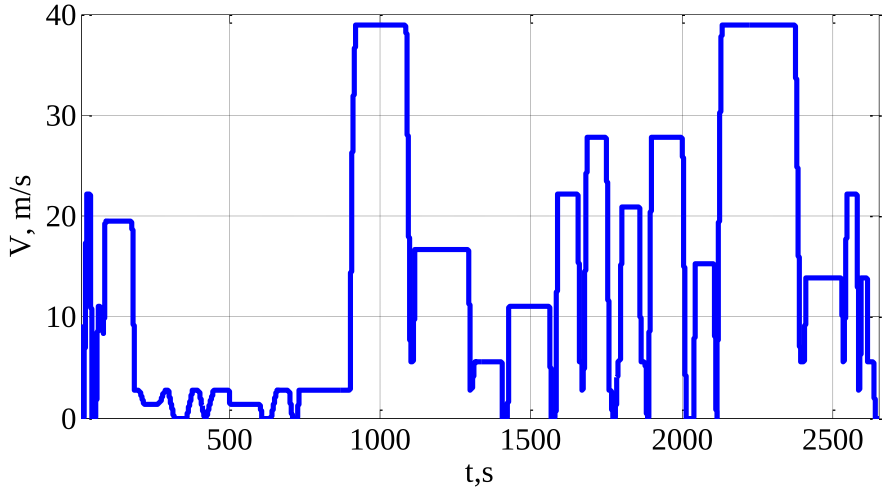

Figure 1 – Driving cycle

To simulate vehicle performance, motion equations have to be obtained. It can be done by analyzing all forces, acting on the vehicle during its motion. For a mathematical representation of the vehicle, a simplified model is used and shown in Fig. 2. Only forces of the movement along the longitudinal and vertical axes are considered [3].

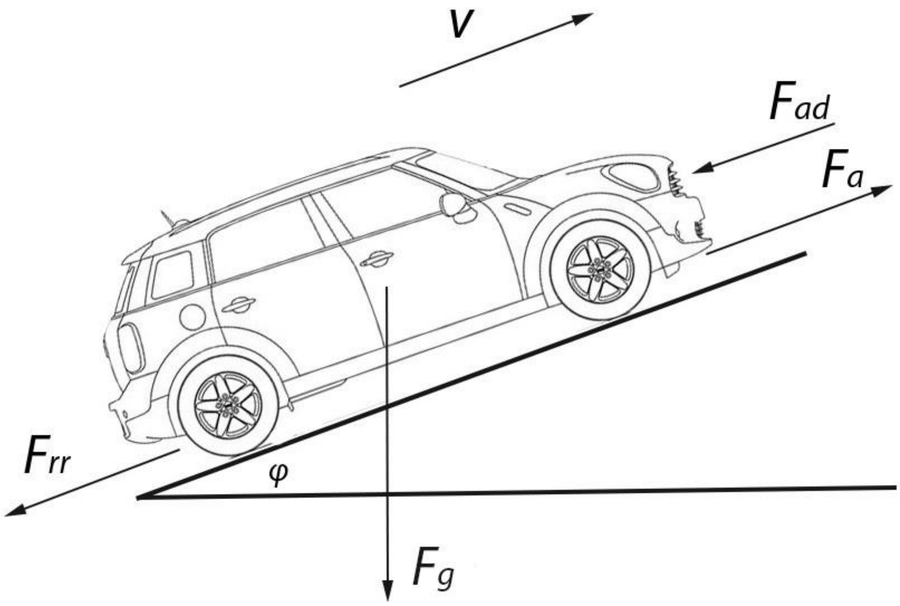

Figure 2 – Mechanical forces, that act on the vehicle

Force, propelling the vehicle forward, is called tractive effort F_T [4]. It includes both static and dynamic components, and can be calculated by the following equation:

$$F_T = F_{rr} + F_{ad} + F_g + F_a, \qquad (5)$$

where F_{rr} is the rolling resistance force, F_{ad} is the aerodynamic drag, F_g is the grade resistance, F_a is the acceleration force. If provided traction power is big enough to overcome the listed above resistance forces, the vehicle will propel forward.

The rolling resistance force is a result of the vehicle tire and the road surface contact. It does not depend on the vehicle speed and can be assumed constant. The equation that describes the rolling resistance force is as follows:

$$F_{rr} = fmg\cos\varphi, \qquad (6)$$

where f is the rolling resistance coefficient, m is the vehicle mass, g is the acceleration of gravity, φ is the road slope. For simplicity, in this paper, the road slope is considered to be equal to zero ($\cos\varphi = 1$).

The rolling resistance force results in:

$$F_{rr} = fmg\cos\varphi = 0.01 \cdot 1440kg \cdot 9.81m/s^2 = 141.3\ (N). \qquad (7)$$

Aerodynamic drag depends on the air density ρ, the aerodynamic drag coefficient C_x, the vehicle frontal area S , and vehicle speed v, as follows:

$$F_{ad} = 0.5C_x S\rho v^2, \qquad (8)$$

Since this force depends on the velocity, it will vary during the simulation of the driving cycle. For this purpose, let us consider the aerodynamic drag coefficient $k_{ad} = 0.5C_x S\rho,$ which is equal to:

$$k_{ad} = 0.5C_x S\rho = 0.5 \cdot 0.32 \cdot 1.83m^2 \cdot 1.29kg/m^3 = 0.38\ \left(\frac{kg}{m}\right). \qquad (9)$$

Grade resistance occurs when the vehicle is moving up a slope. It is defined by:

$$F_g = mg\sin\varphi. \qquad (10)$$

Assuming the road slope is zero, the grade resistance is also equal to zero.

Acceleration force is needed to move the vehicle. It is described by Newton's second law:

$$F_a = ma. \qquad (11)$$

Tractive power is defined as a function of linear speed and tractive force, as follows:

$$P_w = v \cdot F_T, \tag{12}$$

Tractive power during the driving cycle is shown in Fig. 3.

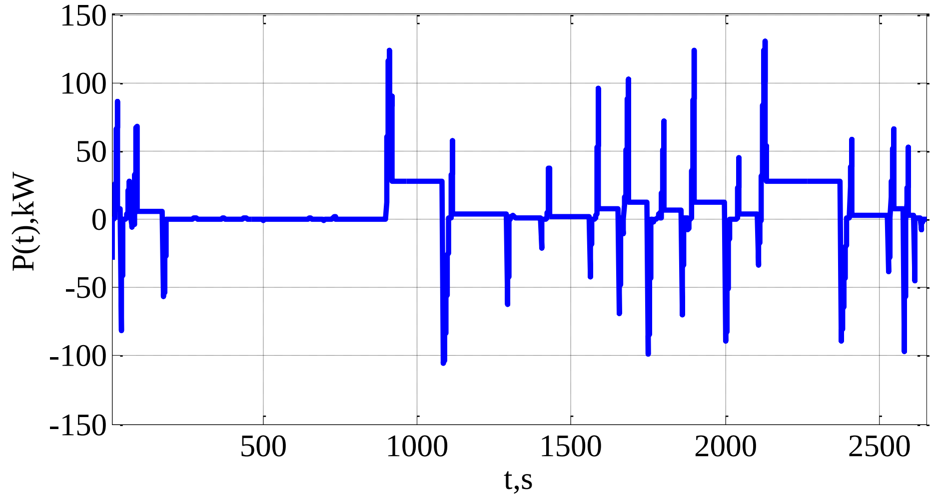

Figure 3 – Tractive power of the vehicle during the driving cycle

Torque, which has to be produced by the traction motor, is given by:

$$T = \frac{F_T \cdot r_w}{i}, \tag{13}$$

where *i* is the reduction gear ratio.

From (13), the torque during the driving cycle was computed. It is shown in Fig. 4.

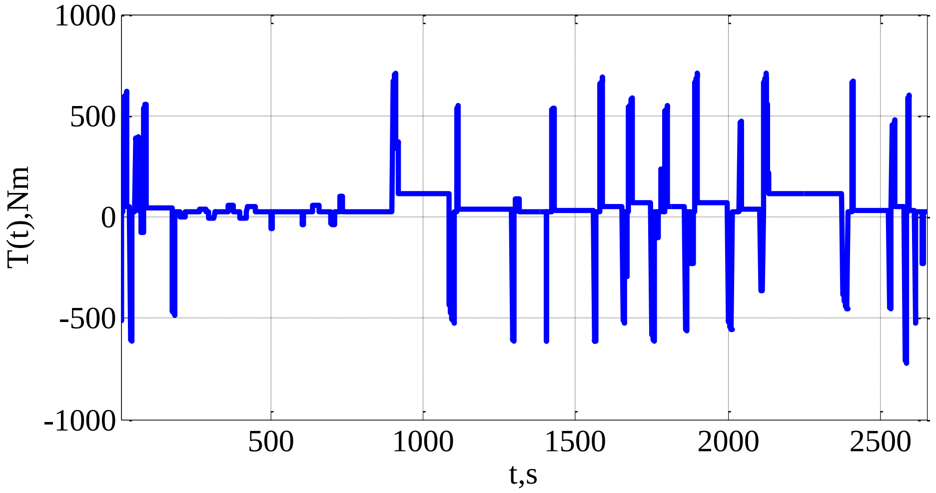

Figure 4 – Motor torque during the driving cycle

For further calculations, equivalent torque should be known. It is calculated via numerical integration of torque function $T(t)$. The equation that describes it is as follows [5]:

$$T_{equiv} = \sqrt{\frac{1}{t_{drc}} \int_0^{t_{drc}} T^2(t) dt}, \tag{14}$$

where t_{drc} is driving cycle time.

From the above expression (14), it follows:

$$T_{equiv} = 177.5 \ (Nm). \tag{15}$$

The maximal angular rotational speed of the motor can be computed by the following equation:

$$\omega_{\max} = \frac{v_{\max} \cdot i}{r} = \frac{38.9 m/s \cdot 2}{0.3m} = 258.6 \ (rad/s). \tag{16}$$

Power, which the motor has to produce in order to propel the vehicle forward during the selected driving cycle, is described by:

$$P_m = k_s T_{equiv} \omega_n, \tag{17}$$

where $k_s = 1.1 \div 1.3$ is the safety factor, ω_r is the motor rated angular speed.

Let us assume that a vehicle rated linear speed is 100 km/h, or 27.8 m/s. Then, the rated angular speed of the traction motor is given by:

$$\omega_r = \frac{v_{vr} \cdot i}{r_w} = \frac{27.8 m/s \cdot 2}{0.3m} = 185.3 \left(\frac{rad}{s} \right). \tag{18}$$

Now the traction motor power, which satisfies the chosen driving cycle, can be calculated according to (17):

$$P_m = 1.2 \cdot 177.5 Nm \cdot 185.3 rad/s = 39.5 \ (kW). \tag{19}$$

Battery power P_{bat}, needed for one driving cycle, is given by [6]:

$$P_{bat} = \frac{P_{mot}}{\eta_{red} \cdot \eta_{inv} \cdot \eta_{mot}}, \tag{20}$$

where P_{mot} is the traction motor power, η_{red} is the reduction gear efficiency, η_{inv} is the inverter efficiency, η_{mot} is the traction motor efficiency.

Energy W_{bat}, needed for one driving cycle is given by:

$$W_{bat} = \int P_{bat}. \tag{21}$$

And total battery power, needed for the full range is given by:

$$P_{bat} = \frac{4 \cdot W_{bat}}{3600} = 28.2 \left(kW\right). \tag{22}$$

Conclusion. In this article, parameters calculation of traction motor and battery pack for electric vehicle application is presented. The obtained electromechanical system is based on Mini Countryman 1.5 MT One and requires 39.5 kW traction motor and 28.2 kW battery pack.

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