Electric Vehicle Chassis Simulation Model in MATLAB/Simulink

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Abstract. Nowadays, there has been an active growth of interest in the development and use of vehicles based on the utilization of electric energy. Electric vehicles are actively being studied and then introduced into everyday life. A large number of studies are aimed at improving the existing design of vehicle components, units, and mechanisms. In this paper, we study a simulation model of an electric vehicle moving along a road with an irregular profile. We use the example of an electric vehicle chassis equipped with an electric motor and an energy storage device, taking into account the change in energy spent on moving along the road, considering the rises and descents, as well as the influence of speed modes under given conditions. The model takes into account air resistance and friction forces acting on the units of the car during movement. The model is implemented in the MATLAB/Simulink environment and can be useful in determining the electric drive parameters of an electric vehicle, analysing the electrical system, and studying the efficiency of vehicle operation.

1. Introduction

Computer simulation allows us to study intelligent simulation models of production and logistics systems, analyze their characteristics, and optimize performance. A digital model makes it possible to conduct virtual experiments and answer the question “What if?” with no change in the operation of the current system or before investing in construction and new production equipment. Computer simulation modeling is a way to play out a model over time and animate its behavior [1-5].

Recently, there is an increase in the number of papers related to the development and investigation of simulation models of electric vehicle components. For example, in [6-9], the stages of the study of the car chassis simulator are described. In the beginning, virtual prototyping is applied for transmission systems of mechanism structures and short cyclic tests of efficiency and energy saving are conducted. The model properties of each transmission element are set, and then tested for compliance with the specified characteristics of the system. As a result of the study, a complete virtual simulation model of the chassis is created [10-12].

In addition to the transmission and chassis models, electric motors, batteries, and bodies in new designs are studied in [12-14].

Thus, using specialized software products such as MATLAB/Simulink, it is possible to evaluate the behavior of a real object in various situations with fairly high accuracy. Many high-tech enterprises...
use the construction of a digital model as a required step in the design of objects and systems, since the
digital model saves the money that would have been spent on building a prototype. Computer
modeling allows you to quickly change the design of a digital object and check the necessary
characteristics without using special test rigs, platforms and proving grounds.

2. Theoretical study
The theoretical study consists in establishing the relationship between the input and output parameters
of an electric vehicle model. The result of this study should be a mathematical model that can be used
to describe the movement of an electric vehicle. The mathematical model must take into account the
facts that the electric vehicle is moving along a road with a certain profile, and air drag and sliding
friction forces affect the vehicle [15-18].

![Figure 1. The road profile.](image1.png)

![Figure 2. The forces acting on the vehicle.](image2.png)

It follows from Newton's second law of motion:

$$a = \frac{\sum F}{m}$$  \hspace{1cm} (1)

where $a$ is the vehicle acceleration, m/s$^2$; $F$ are forces acting on the body, N; $m$ is the vehicle weight,
kg.

The sum of forces acting on the body includes the traction force and drag forces, such as the rolling
friction force and air drag force. Therefore, we can rewrite equation (1) as follows:

$$a = \frac{F_T + F_D + F_{FF} + m \cdot g \cdot \sin \alpha}{m}$$  \hspace{1cm} (2)

where $F_T$ is the traction force, N·m; $F_D$ is the drag force, N·m; $F_{FF}$ is the rolling friction force, N·m; $g$
is gravity acceleration, m/s$^2$; $\alpha$ is the road grade angle.

We can represent the road profile (Figure 1) as a graph of some function $h=f(l)$. Having taken a
derivative of this function, we can find the tangent of the angle of tangent slope, that is, the angle of
the road profile surface slope $\alpha$. The equation for finding the angle $\alpha$ is:

$$\alpha = \arctan \left( \frac{dy}{dx} \right)$$  \hspace{1cm} (3)

The car traction force is formed by transmitting rotation from the engine to the wheels of an
electric vehicle. Traction force is determined by the equation (4):
\[ F_r = \frac{2M}{D} \quad (4) \]

where \( M \) is wheel torque, N\cdot m; \( D \) is the wheel diameter, m.

Wheel torque of an electric vehicle can be determined using the basic equation of the dynamics of rotational motion:

\[ M = J \frac{d\omega}{dt} \quad (5) \]

where \( J \) is the equivalent moment of inertia of transmission, kg\cdot m\(^2\); \( \omega \) is the engine shaft speed frequency, rad/s.

Knowing the equation describing the acceleration of an electric vehicle, we can find an equation describing the speed and path of an electric vehicle over time:

\[ v = \int a \, dt \quad (6) \]
\[ s = \int v \, dt \quad (7) \]

The force of aerodynamic drag [13]:

\[ F_D = \frac{\rho \cdot v^2}{2} S_{\text{eff}} \quad (8) \]

where \( \rho \) is air density, kg/m\(^3\); \( v \) is the vehicle speed, m/s; \( S_{\text{eff}} \) is the effective drag area of the vehicle, m\(^2\).

The force of rolling friction is:

\[ F_{\text{ff}} = \frac{2 \cdot f \cdot N}{D} \quad (9) \]

where \( f \) is the coefficient of rolling friction, m; \( N \) is the support reaction force, N; \( D \) is the wheel diameter, m.

3. Experimental study

Using equations (1-8) in the MATLAB/Simulink software environment, we obtain the simulation model of the chassis. The numerical values of the model parameters are given in Table 1.

| \( m \) (kg) | \( D \) (mm) | \( J \) (kg\cdot m\(^2\)) | \( g \) (m/s\(^2\)) | \( f \) (m) | \( \rho \) (kg/m\(^3\)) | \( S_{\text{eff}} \) |
|------------|-------------|-----------------|----------------|--------|----------------|---------|
| 1500       | 600         | 50              | 9.8            | 0.018  | 1.2            | 1.0     |

To analyse the model, we establish the constant speed condition regardless of the road profile. To do this, we use a proportional-integral-differential controller that changes the current in the winding of the driving motor to maintain a given speed during movement. We take the distance covered, vehicle speed, and traction force as measurement parameters. Figures 3-5 show the results of the model experiment. Figure 3 presents the graph of the travelling time-dependent changes in the road profile. Figure 5 demonstrates the travelling time dependence of the speed while Figure 6 shows the graph of the traction force changes.
Figure 3. Time-dependent changes in the road profile.

Comparing the graphs in figures 3-5 we see that the greatest power is required at the initial stage, when the traction force is maximum.

Figure 4. Time-dependent changes in the road profile.

This is because the initial speed of the vehicle is zero, and in order to achieve a given speed, a large amount of energy must be imparted to the vehicle.

Figure 5. The results of the traction force calculation.

At the stage of rise in the road \((t_1, t_2)\), the motion resistance force increases and the speed begins to decrease. At the same time, the speed controller that simulates the driver, increases the traction force and restores the speed. At the descent stage \((t_2, t_3)\), the drag force decreases, the speed increases, the controller reduces the traction force and the speed is restored to the set value.

4. Results and conclusion
As a result of the study, a mathematical model of the chassis of the vehicle was developed, taking into account the change in energy spent on the road movement with regard to the rises and descents, as well as the influence of the speed mode under the given conditions. The model also takes into account air drag and friction forces acting on the vehicle components while driving.

Based on the mathematical model, a simulation computer model was developed in the MATHLAB/Simulink software environment. The simulation results showed that the model allowed us
to study the change in the required parameters. The results obtained in the course of numerical experiments show that changes in the road profile implied changes in the motion resistance force. This leads to a change in speed, introducing disturbance into the steady state mode. To compensate for this disturbance, a change in the traction force is required, which can be achieved by changing the current in the winding of the driving motor. Analysing the change in current, we can estimate the cost of electrical energy required to pass a given section of the road.

The proposed model can be useful in determining the parameters of the electric drive of an electric vehicle, analysis of the electrical system, and the study of the running efficiency of a vehicle equipped with an electric motor and energy storage device, as well as in determining the battery capacity necessary for an electric vehicle to pass a given section.

5. References
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