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COMPUTER SIMULATION OF ELECTRIC VEHICLE ACCELERATION PROCESSES WITH DIFFERENT POSITIONS OF THE MASS CENTER

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ABSTRACT

Due to the electrification of modern vehicles the role of the electric drive is growing as the main mover. In conditions of increasing requirements for the safety controllability and energy efficiency of a vehicle on electric traction, it is actual to take into account the dynamic properties of a vehicle in various driving modes when developing an automatic control system. In the work it is investigated the influence of the mass center position on the redistribution of forces during acceleration on a straight-line section. Taking into consideration the position of the mass center in the control system allows redistributing the desired moment to the wheels with better adhesion to the surface, which increases the safety and controllability of the vehicle, as well as minimizes energy costs on wheels with the worst adhesion. The aim of the work is to investigate the influence of the mass center position on the dynamics of a vehicle with full, rear and front wheel drive using computer simulation. The mathematical description includes analytical expressions for the redistribution of the support reactions for each of the wheels, which makes it possible, on their basis, to carry out computer simulation of the electric vehicle acceleration on a straight-line section. For the indicated types of vehicle drives, a computer model has been developed that includes, in the automatic control system for torque redistribution, the coordinates of the mass center position, which are converted on the basis of analytical expressions into the physical parameters of the system. Computer simulation of acceleration from zero to one hundred km/h with full pressing of the accelerator pedal for nine different positions of the mass center and three types of drive was carried out. Data were obtained on the change in accelerations, support reactions and torque of wheels during acceleration at various mass center positions. Based on the results obtained, the most preferable coordinates of the mass center for each type of drive from the point of view of the acceleration dynamics on a straight section were determined. The developed computer model can be used to study the dynamics of an electric vehicle when cornering, as well as to study energy indicators in all dynamic driving modes.

Keywords: computer simulation; electric vehicle; electric drive; position of mass center; acceleration process

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INRODUCTION

The appearance of the first electric vehicles (EV) is marked, for the specialty automation and electric drive, the emergence of a new control object – a vehicle. This means that the quality of the automatic control system (ACS) of the traction electric drive in combination with existing safety systems and enhanced vehicle controllability determines: safety of movement, the ability to work out driving influences (controllability); energy costs in various driving modes [1].

The modern model-oriented approach to design allows us to quickly assess the quality of the designed control system and achieve the desired result. Works [2–5] in a practical way confirm the high efficiency of computer modeling as a method of researching control systems in various areas of automation.

Improving the dynamic characteristics and energy efficiency of a EV can be achieved in several ways, among which the use of hybrid energy storage devices in autonomous power supply systems to coordinate fluctuations in electricity generation and consumption [6–9]; taking into account the nonlinearity of the control object in the synthesis of the ACS controller to reduce power consumption from the power source and increase the life of an autonomous object [10–11]; taking into consideration friction forces and aerodynamic resistance of air for specific energy savings depending on motion parameters [12–13]. The importance of matching the control strategy to the driving style is determined by [14]. It is necessary to note the works that determine the seriousness of the issue of working out the mechanical units of the vehicle [15–16], in order to improve safety and controllability.

A number of works devoted to the analysis of vector control systems [17–18], considering an electric vehicle in dynamic driving modes. The work [19] is devoted to taking into account the road situation in ACS, for example, wind loads, slope and rolling friction. Analysis of existing studies dedicated to the ACS vehicle showed insufficient light issue of the research of the influence of the center of mass position on the dynamics of the vehicle. This issue is fully covered in the works regarding the theory of the vehicle [4] as one of the points in the section "Dynamics of the vehicle". In the articles [20–21], a vehicle with various architectures is studied (mass center is one of the layout parameters), vehicle control scenarios are proposed that take into account changes in the center of mass position in order to ensure stability and safety. The work [22], based on the analysis, also confirms the importance of determining the position of the mass center as a parameter that affects the dynamics of the vehicle.

Analysis of the market for modern EV showed that over the past year at least 5 more concepts of electric vehicles with 4-wheel drives appeared, ready for serial production. This trend indicates the successful passage of tests and the possible competitive ability of these electric vehicles both in the price range and in terms of consumer properties, which determines the relevance and feasibility of the practical implementation of the study.

THE AIM OF THE WORK

The main objective of the study is to take into account the redistribution of forces acting on the vehicle, depending on the acceleration and the position of the mass center, which allows to increase the torque on the wheel, which has better adhesion to the surface, which will increase the speed and efficiency of the maneuver.

As a basic traction facility, a 4-wheel drive power plant with which 2-wheel rear and front-wheel drives are compared is taken.

METHODS, RESULTS AND DISCUSS

In this work, it is considered the dynamics of an absolutely rigid vehicle (*Fig. 1*) moving along a straight-line path with a zero angle of inclination of the surface without taking into account rolling friction. The main parameters are: mass of vehicle, dimensions of the EV, including the geometric position of the mass center relative to the dimensions of the vehicle; coefficient of sliding friction; aerodynamic drag coefficient, taken as the average for vehicles. The setting action is presented in the form of the position of the accelerator pedal, which determines the value of the set torsion torque for all drives. The restrictions apply to the set torque values of each wheel are determined taking into consideration the current values of the respective support reactions. The object of the study is a vehicle with various options for the position of the mass center.

The basic equation of vehicle movement is represented by the formula (1):

$$\int \frac{\sum F}{m} dt = V , \qquad (1)$$

where: $\sum F$ – total force acting on the vehicle, N ; m – curb weight, kg ; V – vehicle speed, m/s .

$$\sum F = \sum F_{traction} - F_{AR} , \qquad (2)$$

where: $\sum F_{traction}$ – total traction force on wheels; F_{AR} – air resistance force, N ;

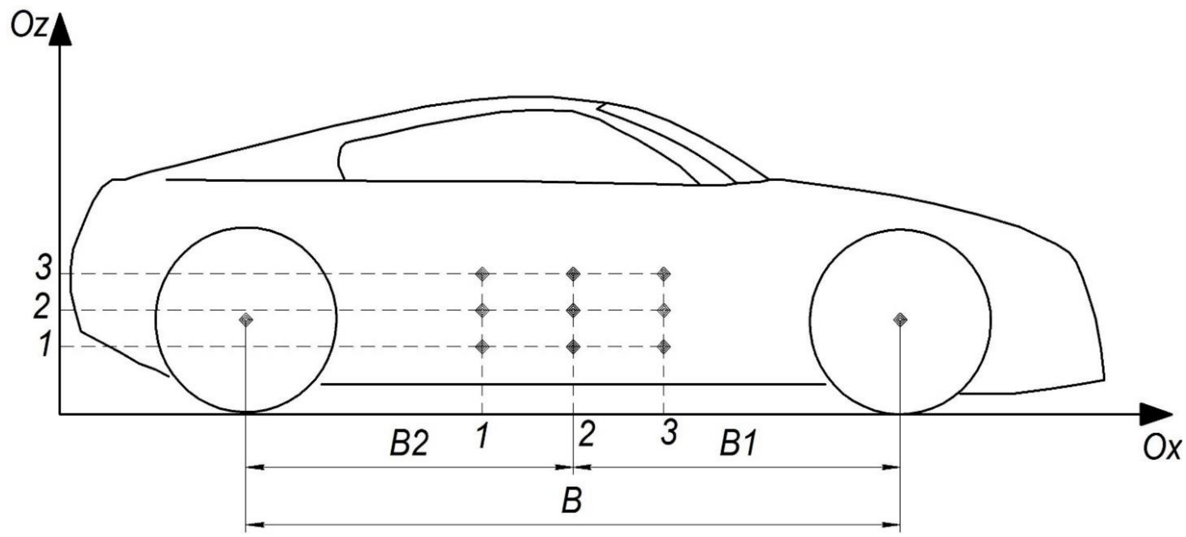

Fig.1. **Control objects with a variable position of the mass center**

$$\sum F_{traction} = F_{LF} + F_{RF} + F_{LR} + F_{RR} - F_{Br}, \quad (3)$$

where: F_{LF} – traction force on the front left wheel, N; F_{RF} – traction force on the front right wheel, N; F_{LR} – traction force on the rear left wheel, N; F_{RR} – traction force on the rear right wheel, N; F_{Br} – force resulting from pressing the brake pedal, N.

In formulas that have the same analytical expressions for each of the wheels, instead of the LF, RF, LR, RR indices the "$wheel$" index is used.

Traction forces on each wheel are described by the formula (4):

$$F_{weel} = \frac{M_{real\_wheel}}{R_{wheel}}, \quad (4)$$

where: M_{real_wheel} – real torques on the motor shaft of each of the wheels, $N \cdot m$;
R_{wheel} – the radius of the respective wheels, m.

Aiming to avoid slipping, the task for drive is limited. The condition for the absence of slipping for traction force ($F_{traction}$) is inequality (5), for torque – inequality (6), where $F_{friction\_wheel}$ – force of sliding friction

$$F_{traction} \le F_{friction}, \quad (5)$$

$$M_{preset\_wheel} \le M_{\lim\_wheel}, \quad (6)$$

where: M_{preset_wheel} – torque set value, $N \cdot m$; $M_{\lim\_wheel}$ – limited torque value excluding slipping, $N \cdot m$.

From (5–6) it follows that M_{preset_wheel} is determined by the degree of pressing the accelerator pedal (AP) and the maximum possible value of the torque $M_{\max}$ (7), and $M_{\lim\_wheel}$ – depends on the sliding friction force ($F_{friction\_wheel}$), which is reflected in (8):

$$M_{preset\_wheel} = AP \cdot M_{\max}, \quad (7)$$

$$M_{\lim\_wheel} = F_{friction\_wheel} \cdot R_{wheel}. \quad (8)$$

In turn, $F_{friction\_wheel}$ is determined (9):

$$F_{friction\_wheel} = N_{wheel} \cdot \mu, \quad (9)$$

where: μ – coefficient of sliding friction; N_{wheel} – support reactions of each of the wheels, N.

Considering that in the dynamics there is a redistribution of the support reactions, and relying on [23–24], write the formula of the support reaction for the front left (10) and rear left wheel (11). The right front wheel is similar to the left front and rear wheel, respectively.

$$N_{LF} = \frac{m \cdot g \cdot (B_2 / B)}{2} - \frac{\sum F \cdot Z}{B}. \quad (10)$$

$$N_{LR} = \frac{m \cdot g \cdot (B_1 / B)}{2} + \frac{\sum F \cdot Z}{B}. \quad (11)$$

Parameters (B_2 / B) and (B_1 / B) determine the redistribution of weight in statics depending on the position of the mass center along the X axis, and the parameter Z – along the Z axis.

An enlarged block diagram of the automated control system of the EV, effecting distribution torque and created on the basis of the mathematical description and sources [12; 25], is presented in *Fig 2*.

Based on the assumption that the coefficient of sliding friction in (6) is known and the wheels are constantly in adhesion with the road surface, slip processes are not modeled. Electronic traction systems that indirectly determine the coefficient of sliding friction are not the subject of this study.

Subsystem "Sources driving actions" – generates the setting action by choosing the degree of pressing the accelerator pedal (in *Fig. 2* the "AP: Value" slider).

Further, the data on the degree of pressing is sent to the "Torque Assignment Automatic Control System", which limits the value of the setting moment taking into account the redistribution of the reactions of the support and the coefficient of adhesion to the surface. This subsystem corresponds to the formulas (5)-(11) of the mathematical description.

A limited moment is transferred at the "Actuating mechanisms" (*Fig. 5*), subsystem, which is represented by an aperiodic first-order link with a time constant (0.1 s).

Real moments are transferred at the "Control object" subsystem (*Fig. 6*), which are converted into traction forces on wheels (3) – (4), which drive the vehicle with a given mass (1) taking into consideration the force of air resistance (3). The speed of movement is reflected in the visual speedometer (*Fig. 2*).

Developed computer model of the EV ACS, based on the mathematical description, allows studying the influence of the mass center position on the dynamics of the vehicle.

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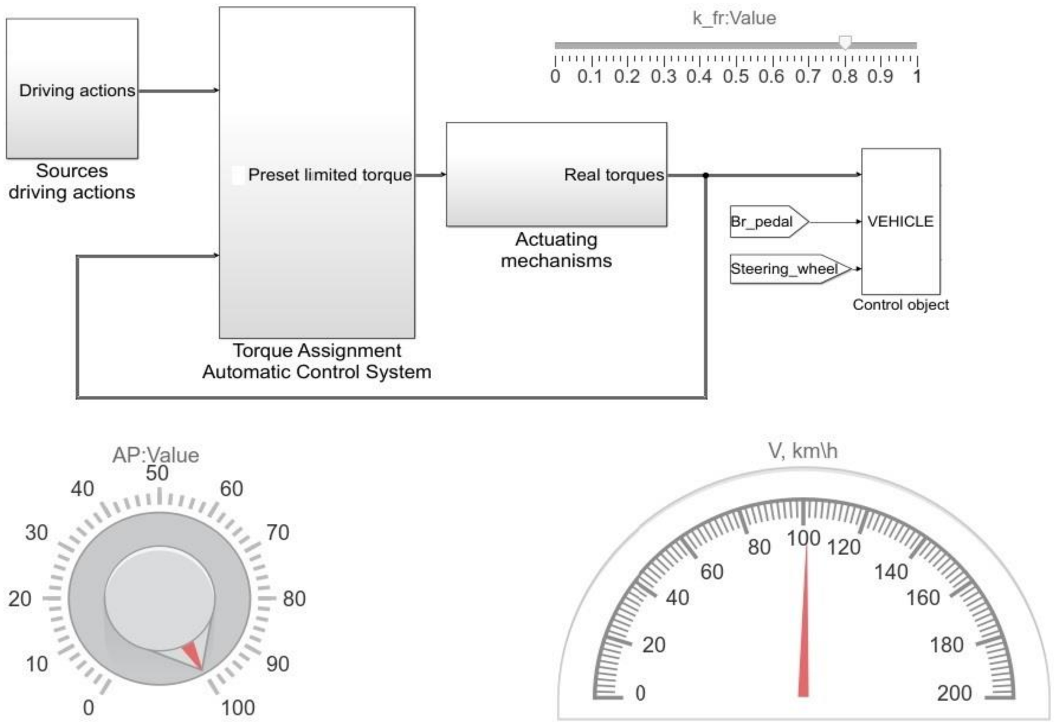

Fig. 2. **The ACS structure of the EV**

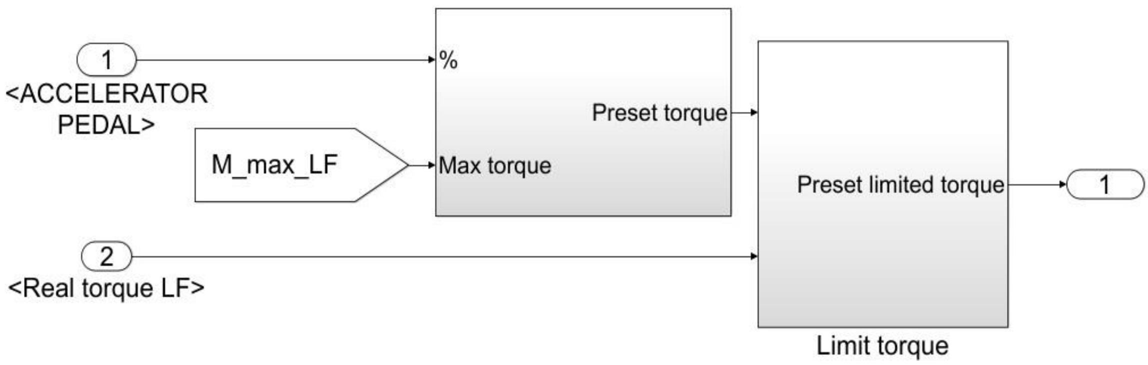

Fig. 3. **Subsystem "Torque Assignment Automatic Control System" represented by the left front wheel**

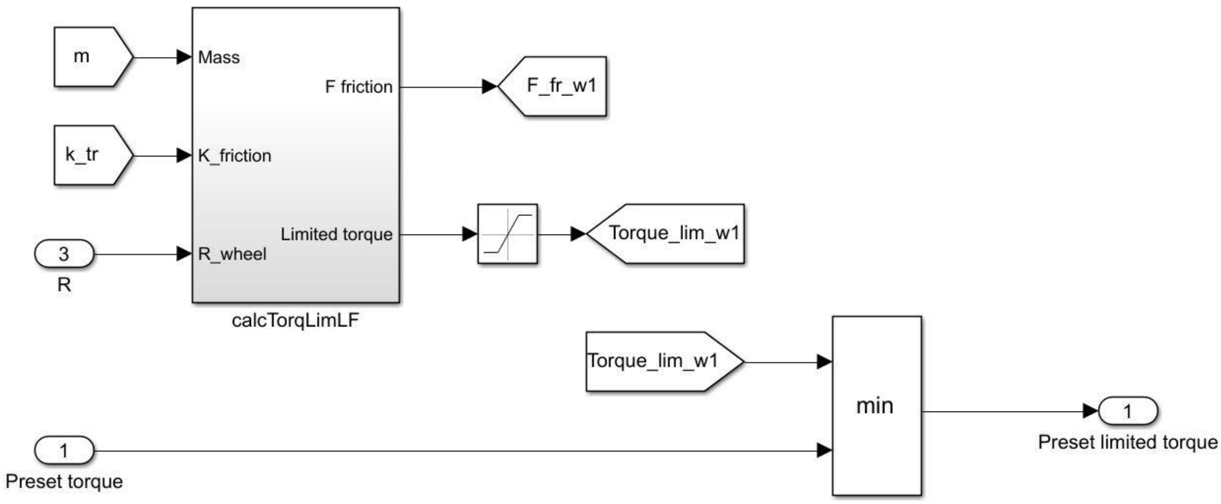

Fig. 4. **"Limit torque" subsystem**

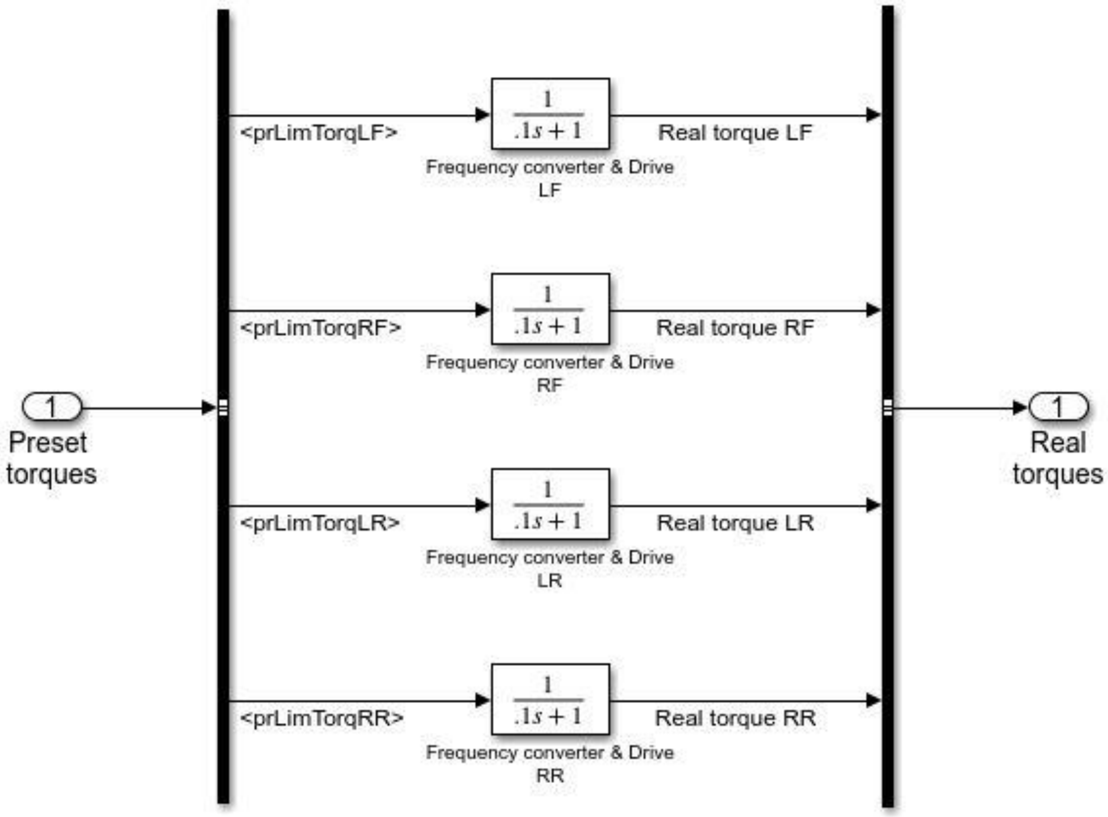

Fig. 5. **"Actuating mechanisms" subsystem**

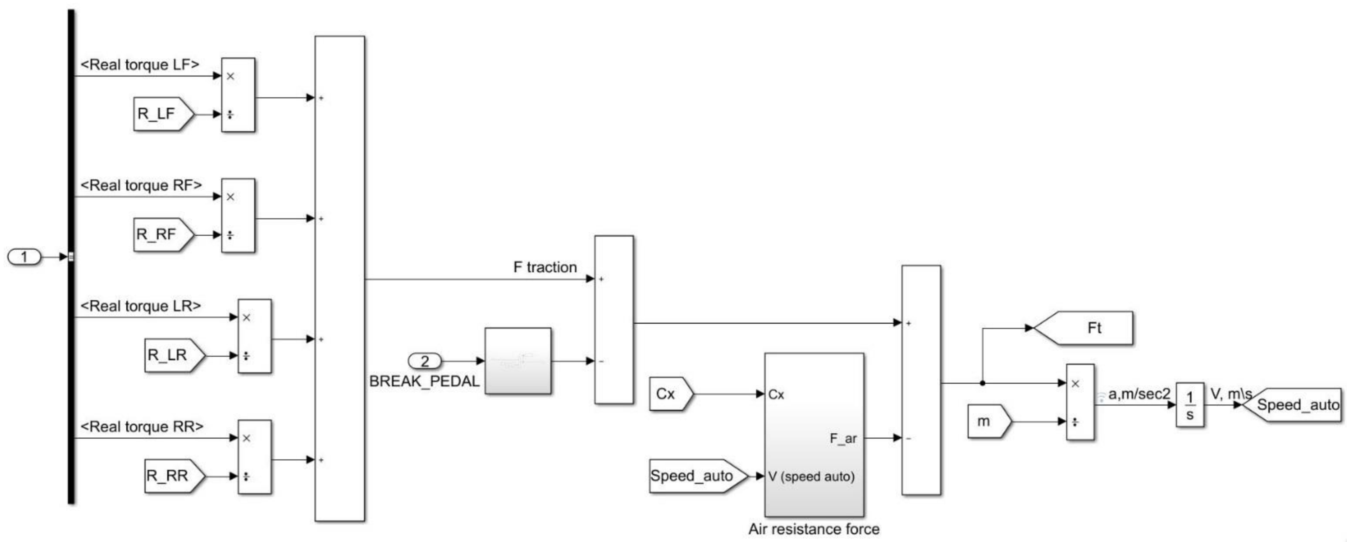

Fig. 6. **"Control object" subsystem**

The basis of the experiments is to change the parameters of the system in accordance with the choice of the coordinate of the mass center (*Fig.7*)

The step of changing of the mass center position is taken on the basis of the various layout options study of existing vehicles.

In this work, the influence of the mass center position on vehicle dynamics is studied for 3 different drive configurations, namely: all-wheel (4 drives), rear (2 drives on the rear wheels) and front (2 drives on the front wheels).

Mathematical modeling was carried out under the following initial conditions: vehicle mass – 1730 kg; vehicle base – 2.87 m; aerodynamic drag coefficient – 0.25; coefficient of friction with the surface – 0.8; radius of the wheel – 0.33 m; for a 4-drive vehicle, the maximum torque for each of the

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wheels is – 925 $N \cdot m$, for a rear-wheel drive – 1850 $N \cdot m$ for each of the rear wheels and for front-wheel drive – 1850 $N \cdot m$ for each of the front wheels.

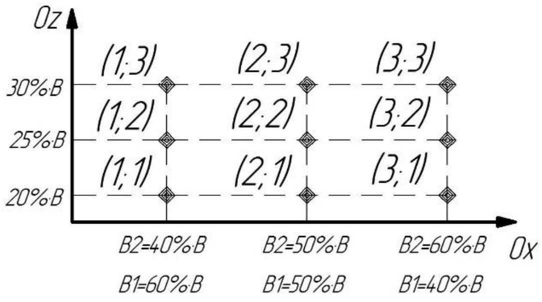

Fig. 7. **Positions coordinates of the mass center, parametrizing ACS of the EV**

Computer simulation of acceleration from 0 to 100 km/h with 100 % pressing the accelerator pedal for 9 different positions of the mass center and 3 different drives was carried out. As a result, the following data were obtained: acceleration time to 100 km/h; the nature of the change and the maximum achievable acceleration during acceleration; changes in the support reactions on the front and rear wheels; changing the values of the limited moments on the front and rear wheels.

The results are presented in the form of graphs (*Fig. 8, Fig. 9* and *Fig. 10*) of the preferred positions of the mass center of the indicated types of drives and in the form of *Table 1*, which reflects the result of acceleration for all 9 points of each type of drive.

The graphs of moments and efforts show two lines: blue solid – front wheels, red dotted – rear wheels.

Table 1. **Simulation results**

Oz	t, s			Type drive
3	6.84	6.10	5.52	**4-drive**
2	6.49	5.79	5.25	
1	6.14	5.49	5.00	
3	4.73	4.73	5.07	**Rear**
2	4.73	4.74	5.78	
1	4.73	5.23	6.49	
3	13.80	10.98	9.13	**Front**
2	13.06	10.39	8.65	
1	12.32	9.81	8.17	
Ox	1	2	3	

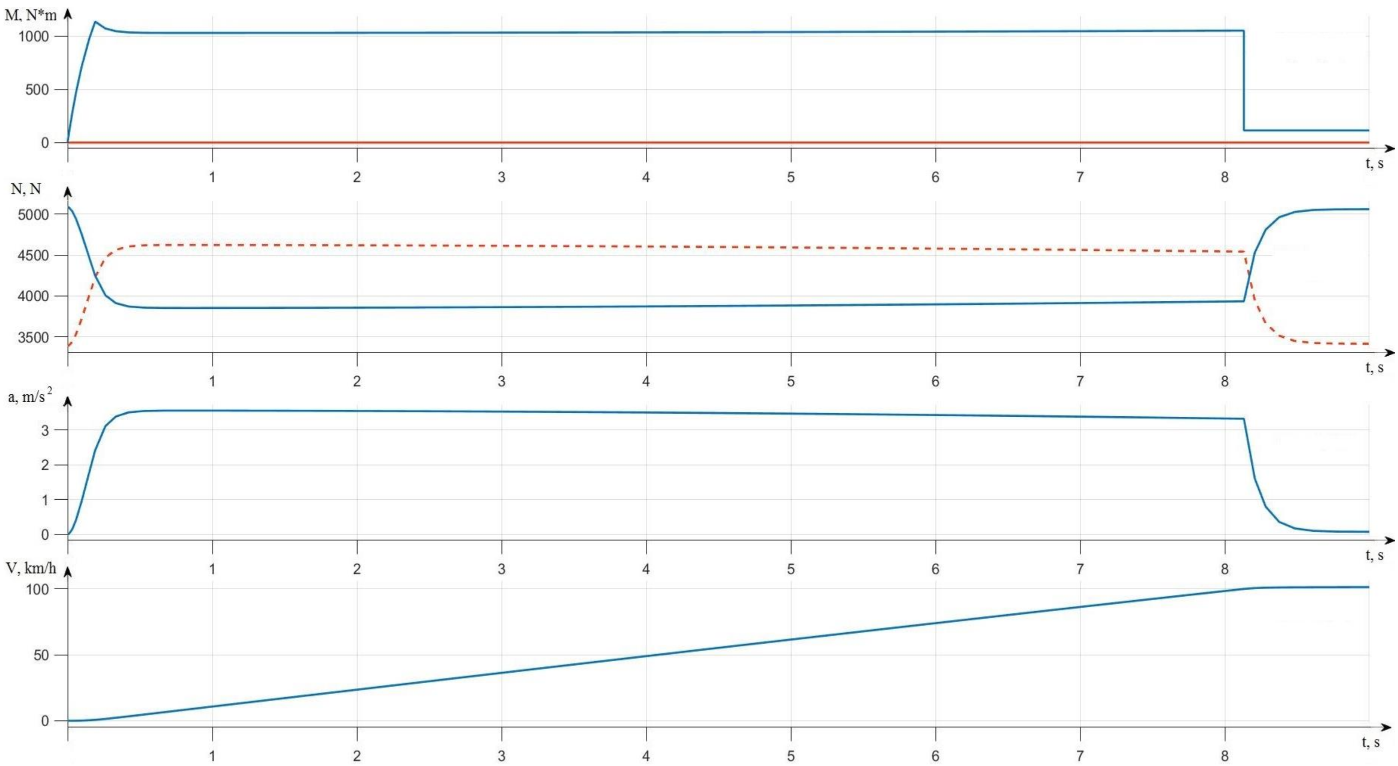

Fig. 8. **Acceleration dynamics of a front-wheel drive vehicle with the coordinates of the mass center (3; 1)**

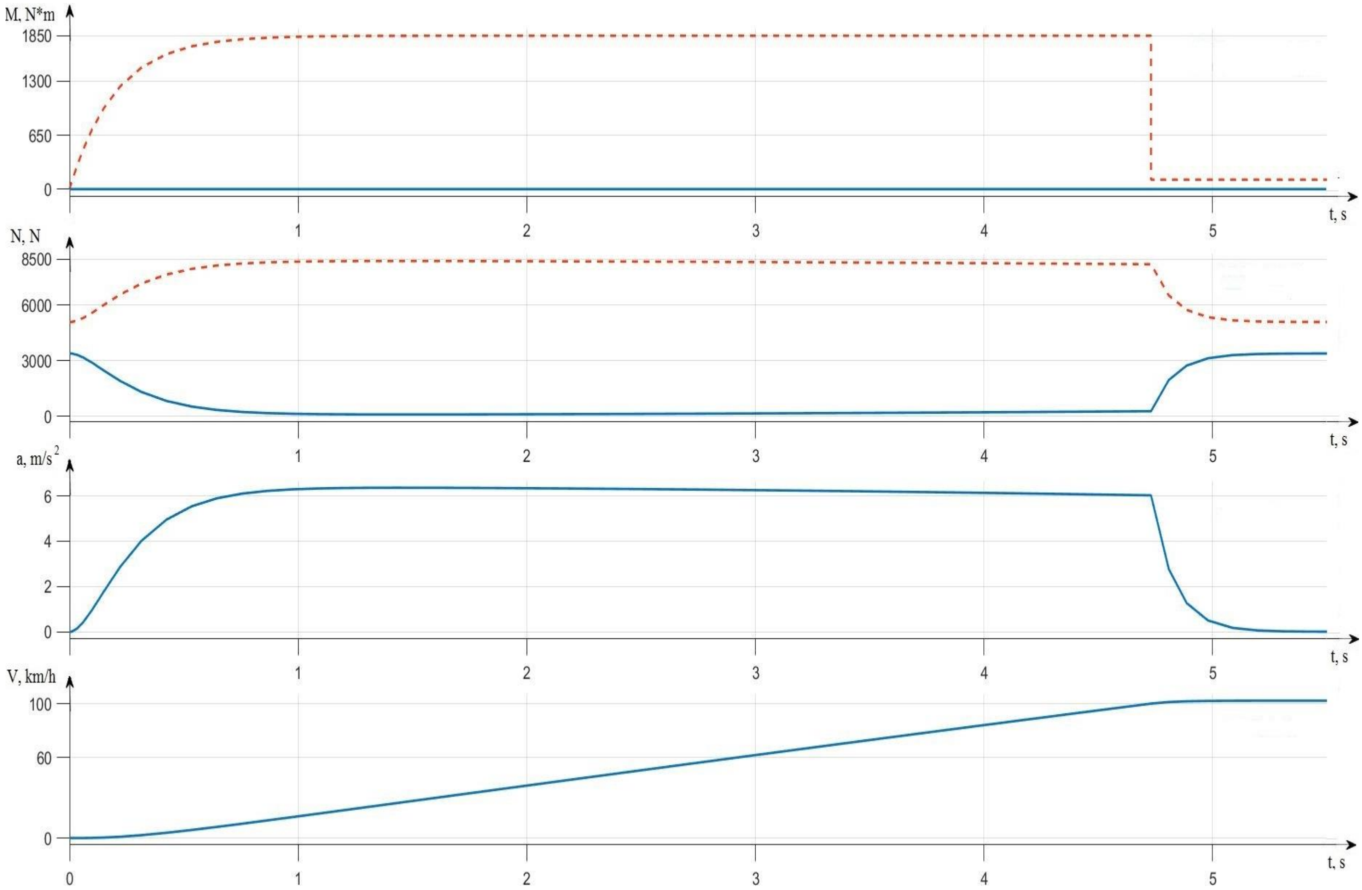

Fig. 9. **Acceleration dynamics of a rear-wheel drive vehicle with coordinates of the mass center (1; 3)**

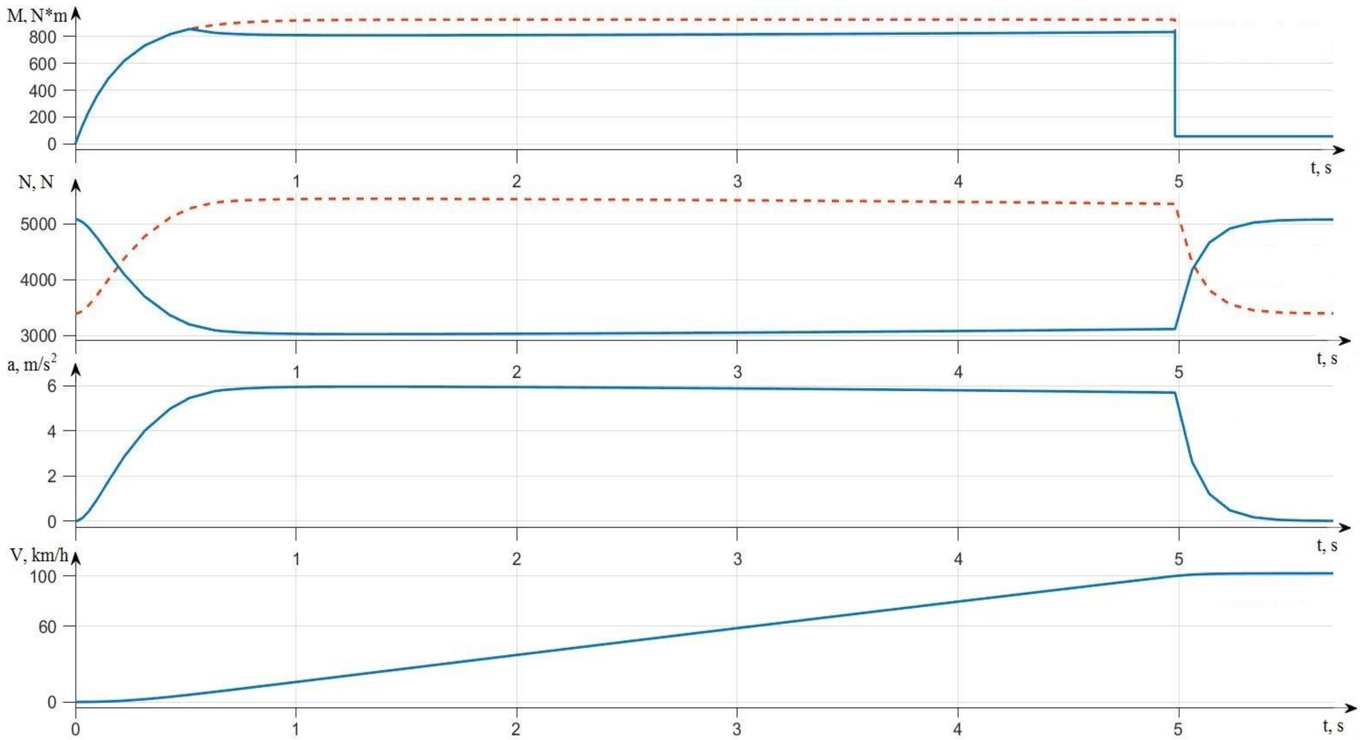

Fig. 10. **Acceleration dynamics of a 4-drive configuration with coordinates of the mass center (3; 1)**

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CONCLUSION

The results of computer simulation showed that the preferred coordinates of the center of mass position for the front drive (*Fig. 8*) are shifted closer to the front axle (3; 1), however, in comparison with the rear and all-wheel drive, the front-wheel drive is the least effective in terms of acceleration dynamics at straight-line section.

The best indicators of maximum acceleration and acceleration time are achieved with a rear-wheel drive with the coordinates of the center of mass – (1; 3). But this result is accompanied by close to zero values of support reactions (*Fig. 9*), which is undesirable from the point of view of vehicle controllability. Full-drive with dislodged to the front mass center (3; 1) reaching close values to the best acceleration dynamics result and providing about 60 % of the vehicle weight on the front axle is the most preferable (*Fig. 10*).

The research result allows choosing the type of drive with the best dynamics for various vehicle configurations (sedan, station wagon, jeep) and vice versa, selects the appropriate arrangement for various drives that implements the capabilities of the traction unit as efficiently as possible from the point of view of acceleration.

Further research should be continued in the direction of determining the influence of the mass center position on the dynamics of the vehicle during rotation.

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КОМП'ЮТЕРНЕ МОДЕЛЮВАННЯ ПРОЦЕСІВ РОЗГОНУ ЕЛЕКТРИЧНОГО ТРАНСПОРТНОГО ЗАСОБУ З РІЗНИМ РОЗТАШУВАННЯМ ЦЕНТРУ МАС

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АНОТАЦІЯ

У зв'язку з електрифікацією сучасних транспортних засобів зростає роль електроприводу як основного рушія. В умовах підвищення вимог до безпеки, керованості і енергоефективності транспортного засобу на електротязі, актуальним при розробці системи автоматичного керування є врахування динамічних властивостей транспортного засобу в різних режимах їзди. В роботі досліджується вплив положення центру мас на перерозподіл сил при розгоні на прямолінійній ділянці дороги. Врахування положення центру мас в системі керування дозволяє перерозподіляти бажаний момент на колеса з кращим зчепленням з поверхнею, що підвищує безпеку і керованість транспортного засобу, а також мінімізує енергетичні витрати на колесах з гіршим зчепленням. Мета роботи - дослідити методом комп'ютерного моделювання вплив положення центру мас на динамку транспортного засобу з повним, заднім і переднім приводом. Математичний опис включає в себе аналітичні вирази перерозподілу реакцій опор для кожного з коліс, що дозволяє на їх основі провести комп'ютерне моделювання розгону електричного транспортного засобу на прямолінійній ділянці. Для зазначених типів приводів транспортних засобів розроблена комп'ютерна модель, що включає в системі автоматичного керування перерозподілу крутного моменту координати положення центру мас, що перетворюються на підставі аналітичних виразів в фізичні параметри системи. Проведено комп'ютерне моделювання розгону від нуля до ста км / год при повному натисканні на педаль акселератора для дев'яти різних положень центру мас і трьох типів приводу. Отримано дані про зміну прискорень, реакцій опор і обертаючих моментів коліс в процесі розгону при різних положеннях центру мас. На підставі отриманих результатів визначено найкращі з точки зору динаміки розгону на прямолінійній ділянці координати центру мас для кожного типу приводу. Розроблену комп'ютерну модель можна використовувати для дослідження динаміки електричного транспортного засобу при повороті, а також дослідити енергетичні показники у всіх динамічних режимах руху.

Ключові слова: комп'ютерне моделювання; електричний транспортний засіб; електропривод; положення центру мас; процес розгону

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КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ ПРОЦЕССОВ РАЗГОНА ЭЛЕКТРИЧЕСКОГО ТРАНСПОРТНОГО СРЕДСТВА С РАЗНЫМ РАСПОЛОЖЕНИЕМ ЦЕНТРА МАСС

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АННОТАЦИЯ

В связи с электрификацией современных транспортных средств растет роль электропривода как основного движителя. В условиях повышения требований к безопасности, управляемости и энергоэффективности транспортного средства на электротяге, актуальным при разработке системы автоматического управления является учет динамических свойств транспортного средства в различных режимах езды. В работе исследуется влияние положения центра масс на перераспределение сил при разгоне на прямолинейном участке дороги. Учет положения центра масс в системе управления позволяет перераспределять желаемый момент на колеса с лучшим сцеплением с поверхностью, что повышает безопасность и управляемость транспортного средства, а также минимизирует энергетические затраты на колесах с худшим сцеплением. Цель работы – исследовать методом компьютерного моделирования влияние положения центра масс на динамку транспортного средства с полным, задним и передним приводом. Математическое описание включает в себя аналитические выражения перераспределения реакций опор для каждого из колес, что позволяет на их основе провести компьютерное моделирование разгона электрического транспортного средства на прямолинейном участке. Для указанных типов приводов транспортных средств разработана компьютерная модель, включающая в системе автоматического управления перераспределения крутящего момента координаты положения центра масс, преобразующиеся на основании аналитических выражений в физические параметры системы. Проведено компьютерное моделирование разгона от нуля до ста km/h при полном нажатии на педаль акселератора для девяти различных положений центра масс и трех типов привода. Получены данные об изменении ускорений, реакций опор и вращающих моментов колес в *процессе разгона при различных положениях* центра масс. На основании полученных результатов определены наиболее предпочтительные с точки зрения динамики разгона на прямолинейном участке координаты центра масс для каждого типа привода. Разработанную компьютерную модель можно использовать для исследования динамики электрического транспортного средства при повороте, а также исследовать энергетические показатели во всех динамических режимах движения.

Ключевые слова: компьютерное моделирование; электрическое транспортное средство; электропривод; положение центра масс; процесс разгона

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