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Research of electric car dynamics

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Recently, electric vehicles are becoming widespread throughout the world, so the research is relevant. The results of performed researches of dynamics electric car on the basis of ZAZ-1102 are presented. The calculation method of dynamic loads in electric and mechanical systems of electric cars is developed. The technique considers the electromagnetic processes in the engine, the elasticity of the elastic parts, the oscillatory processes, and damping in the elastic links. On the basis of the developed mathematical model and using the mathematical software apparatus MathCAD, calculations of transients in the electric and mechanical systems have been obtained, based on the obtained results of the research, the constructed graphs. The obtained results of the study of the electric motor drive mechanism can be used for designing, calculating and determining the dynamic loads of electric cars and their hybrids.

Keywords: mathematical model, electric car, drive, mechanical and electrical systems, dynamic loads, flexibility, electromechanical processes, oscillatory phenomena.

Дослідження динаміки електромобіля

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Останнім часом електромобілі набувають поширення в усьому світі, тому проведені дослідження є актуальними. Наведено результати виконаних досліджень динаміки електромобіля на базі ЗАЗ-1102. Запропонована методика розрахунку динамічних навантажень в електричній та механічній системах електромобіля на базі ЗАЗ-1102. У методиці враховано електромагнітні процеси у двигуні, податливість пружних ланок, коливальні процеси, демпфування у пружних ланках. Розроблено нову математичну модель для дослідження динаміки електромобіля. Розрахункову схему електромобіля з приводом наведено у вигляді двомасової пружної системи без урахування податливості нерухомої частини електромобіля, вважаючи, що вона має велику жорсткість. Привід електромобіля забезпечується за допомогою одного електродвигуна. При розгляді динамічних навантажень, які виникають у механізмі привода електромобіля під час його пуску, як основний критерій умов навантаження системи прийнято поворот ведучого колеса з максимальним його навантаженням, тому приведення всіх мас привода, жорсткостей пружних ланок, а також сил здійснено до осі обертання ведучого колеса. Елементи обертових частин привода, ведучі (привідні) колеса які мають значні жорсткості при невеликих розмірах по довжині, прийнято як ланки із зосередженими масами. За допомогою розробленої математичної моделі з використанням математичного програмного забезпечення MathCAD досліджено динаміку пуску привода електромобіля та отримано сили, моменти, прискорення, що виникають у пружних ланках електромеханічної динамічної системи. За допомогою розробленої математичної моделі розраховано перехідні процеси в електричній та механічній системах, побудовано графіки залежностей кутових переміщень, швидкостей і прискорень мас, зміни моменту електродвигуна привода електромобіля від часу, які наведено в цій науковій роботі. Отримані результати досліджень може бути використано при проектуванні, розрахунках та визначенні динамічних навантажень у приводах електромобілів.

Ключові слова: математична модель, електромобіль, привід, механічна й електрична системи, динамічні навантаження, податливість, електромеханічні процеси, коливальні явища.

Introduction

The market for electric cars in the world is gaining momentum. Today, it can be state with confidence, that the future is precisely in the electrified cars. Countries with advanced high-tech industries are interested in environmentally friendly transport and stimulate its development. Large manufacturers of cars and technology companies in China, Sweden, France, the United States, Germany, etc., are planning to expand and improve their products based on state support. Thus, the prospects in the near future of electric cars become wider and more realistic.

If compare an electric car with an ordinary car, where the internal combustion engine is used, it is characterized by a simpler scheme, the minimum number of moving elements. Therefore, the electric car is a more reliable design. The main components of an electric car are as follows: electric motor; rechargeable batteries; simplified transmission; inverter charger on board; electronic control system for structural elements; transformer. Therefore, the electric car components study, including its drive, is relevant.

Review of research sources and publications

Such scientists as Bakhmutov S.V., Karunin A.L., Krutashov A.V., Kapustin A.A., Rakova V.A., Umyashkin V.A., Filkin N.M., Muzafarov R.S., Bazhynov O.V., Smyrnov O.P., Syerikov S.A., Hnatov A.V., Kolyesnikov A.V. and so on devoted their work to the research and analysis of electro and hybrid cars, including their drives to determine the frequency of oscillations. In these works, electric and hybrid cars were described by various calculation schemes and their dynamical systems were considered as one and two mass oscillatory systems that enabled to determine the frequency of oscillations [1 – 4]. The work of foreign scientists Collatc L. [5] and Tondl A.[6], Kluchev V.I., Jagadish H.P., Kodad S.F. [8], Kaplan D. [9] are also devoted to the mechanical systems oscillations frequency determination.

When designing an electric car, the question arises about the evaluation of its run by selecting the design parameters of the traction drive, which includes the parameters of the electric motor, transmission and power supplies [10 – 17].

The developed methods of choosing the design parameters of a traction drive of an electric car to achieve a predetermined mileage are based on well-studied characteristics of batteries (lead-acid, nickel-cadmium and others). Manufacturers of modern traction batteries (nickel-metal hydride, lithium-ion, etc.) at the request of the batteries capacity and other characteristics indicate different conditions of temperature, time and discharge current, which impedes their comparative analysis and leads to ambiguous evaluation of charge-discharge characteristics, which is significantly affected run on electric.

In addition, the previously developed techniques use the simplification of the motion equation of an electric car at constant speed or in cycles that do not correspond to the real conditions of motion.

Therefore, improvement of the calculation methods and choice of structural parameters of an electric car, considering the process of discharging modern traction batteries and a full-scale model of car movement in modern urban conditions, is an actual direction of development of electric car performance characteristics improving during its design.

Definition of unsolved aspects of the problem

An electric car drive can be considered as a oscillational system, in which during the start-up and braking periods there are significant dynamic loads. The requirements for the calculation accuracy of such oscillatory systems need to consider both the individual oscillations of the individual elements and the system as a whole due to the fact that as a result of the own and forced oscillations frequencies coincidence there may be resonance phenomena that cause significant dynamic loads and, as consequence, reduce the durability of structures.

At this time, when calculating electric cars for static and tired strength, their own design oscillations are not considered. However, the carrying capacity of electric car designs can be increased if their design in the calculations considers their oscillations amplitude-frequency characteristics.

Thus, the frequencies and electric car forms designs elements proper oscillations determination enables to compare these frequencies with forced frequencies, as well as to obtain data on the loading of the dynamic system, and thus to ensure the normal operation of car all oscillation parts in modes that are far removed from the resonance.

When designing forming posts and the choice of technological equipment for consolidating the concrete mixtures in the manufacture of reinforced concrete products, the technological capabilities assessment of all varieties of vibration tables with spatial oscillations of the moving frame is required.

Problem statement

The purpose of the article is to highlight the results of the mathematical modeling of oscillatory processes in the electric vehicle drive using mathematical software MathCAD and to determine the dynamic loads on its elements during transient processes in the electric vehicle drive.

Basic material and results

Considering the foregoing, the research of dynamic loads of electric vehicles on the basis of ZAZ-1102 car is conducted at the Department of Building Machines and Equipment Poltava National Technical University Yuri Kondratyuk. The transition processes taking place in the operation of the driving mechanisms of electric cars, largely determine the dynamic load in the elements of the systems are considered. The dynamics of the electric car starting and stopping mechanism processes are significantly influenced by the inertial and rigid parameters of the elements. Start and stop of the electric drive is performed at full load.

When considering the dynamic phenomena that arise during the startup of the electric car drive, in the main case of the system load conditions take the turn of the drive wheel with its maximum load. The calculation scheme of the electric motor drive mechanism loadduring the startup of the car driving mechanism is shown in Figure 1.

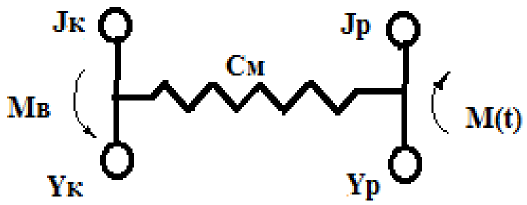

Figure 1 – calculation scheme of the electric motor drive mechanism loading during the startup of the car driving mechanism:

J_P – the electric motor rotor inertia moment, reduced to the axis of drive wheel rotation, considering the masses of rotating mechanisms;
J_K – total moment of inertia of rotating masses relative to the driving wheel rotation axis;
Y_P, Y_K – coordinates of the concentrated masses (angles of reference) motion;
S_M – stiffness of the drive elements are brought

Bringing all the masses of the drive, the stiffness of the elastic parts, and also the forces, the driving wheel rotation axis are made.

The equation of motion is:

$$J_P Y_P'' + C_M(Y_P - Y_K) + J_K (Y_P'' - Y_K'') = vM(t); \quad (1)$$

$$J_K Y_K'' - C_M(Y_P - Y_K) - J_K (Y_P'' - Y_K'') = -vM_{tr}, \quad (2)$$

where $M(t)$ – the moment of an electric motor, which is expressed by differential dependence [7]

$$M(t) = A_0 u + A_1 M'(t) + vA_2 u^2 Y_P(t) \quad (3)$$

A_0, A_1, A_2 – constant electric motor, defined by the expressions:

$$A_0 = 2M_K/S_K, \quad A_1 = 1/\omega_0 S_K, \quad A_2 = 2M_K/\omega_0 S_K \quad (4)$$

M_K – critical moment of the engine;
M_{tr} – moment that creates the total resistance of the electric motor and is brought to the the driving wheel rotation axis
S_K – critical slider of the rotor;
ω_0 – synchronous angular speed of the engine;
v – coefficient characterizing oscillation attenuation;
u – gear ratio of the drive mechanism;
t – time.

For the convenience of solving the equations (1) and (2) system, using the MathCAD software, it is denoted:

$$Y_P = z(t); \quad Y_K = q(t);$$
$$Y_P' = d(t); \quad Y_K' = n(t); \quad (5)$$
$$z'(t) = d(t); \quad q'(t) = n'(t).$$

Then it is got

$$d'(t) = -\frac{C_M}{J_p} z(t) - \frac{v}{J_p} d(t) + \frac{C_M}{J_p} q(t) + $$
$$+ \frac{v}{J_p} n(t) + \frac{1}{J_p} M(t);$$
$$n'(t) = \frac{C_M}{J_K} z(t) + \frac{v}{J_K} d(t) - \frac{C_M}{J_K} q(t) - \quad (6)$$
$$- \frac{v}{J_K} n(t) - \frac{1}{J_K} M_{tr};$$
$$M'(t) = -\frac{A_2 u^2}{A_1} z'(t) + \frac{1}{A_1} M(t) - \frac{A_0 u}{A_1}.$$

Initial conditions are presented in the form

$$t_0 = 0; \quad Y_{K0} = 0; \quad Y_{P0} = 0; \quad M_0 = 0. \quad (7)$$

Generalized technical characteristics of the electric motor and estimated parameters electric driven of the electric vehicles on the basis of ZAZ-1102 car are presented in the table 1.

Table 1 – Generalized technical characteristics of the electric motor and electric driven of the electric vehicles on the basis of ZAZ-1102 car

Parameter		Values of parameters
Type of electric motor		Siemens IP V5135-4WS14
Power of the electric motor, kBt		30
Frequency of the electric motor rotation, r/min		3000
Angle speed rotor of the electric motor, rad / s		314.2
Constant electric motor's	A_0	39470
	A_1	0.3183
	A_2	502.5
Moment of the electric motor rotor inertia J_P, N·m		0.475
Total moment of rotating masses inertia relative to the driving wheel rotation axis J_K, kg·m^2		0.082
Moment that creates the total resistance of the electric motor and is brought to driving wheel rotation axis M_{tr}, N·m		274.8
Gear ratio of the drive mechanism u		3.5
Stiffness of the drive elements are brought S_M, N·m/rad		15150
Coefficient characterizing oscillation attenuation v, м$^{-1}$		823150

Substituting generalized technical characteristics of the electric motor and estimated parameters electric driven of the electric car (Table 1) it is got

$$z'(t) = d(t);$$
$$d'(t) = 0.098M(t) - 1488z(t) - 80860d(t) + 1488q(t) + 80860n(t)\ ; \quad (8)$$
$$q'(t) = n(t);$$
$$n'(t) = 184800z(t) + 10038000d(t) - 184800q(t) - 10038000n(t) - 3351\ ;$$
$$M'(t) = -1670M(t) - 20160d(t) + 453600.$$

As a result of the equations solution (8), the electric motor moment values are obtained, the angular displacement and speed of its rotor and the rotating masses of the drive and their angular accelerations for a given time t (Figures 2 – 7).

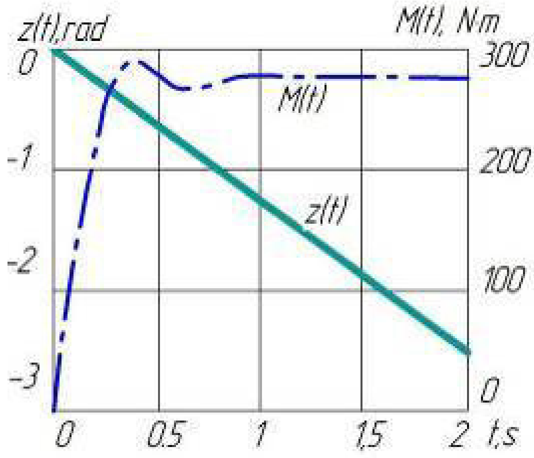

Figure 2 – The change dependences graphs of the angular displacement of the masses brought to the drive wheel rotation axis $Y_P = z(t)$ and the momentary change of the electric car motor drive of the car $M(t)$ as functions of time t

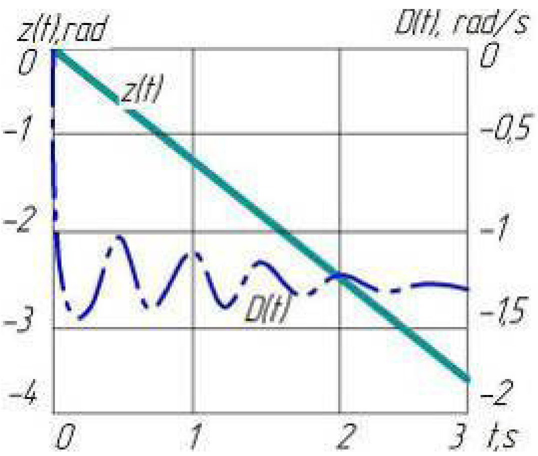

Figure 3 – The dependences graphs of the angular displacement change of the masses brought to the rotation axis of the drive wheel $Y_P = z(t)$ and the angular velocity change of the car electric motor drive $Y_r' = z'(t) = D(t)$ as functions of time t

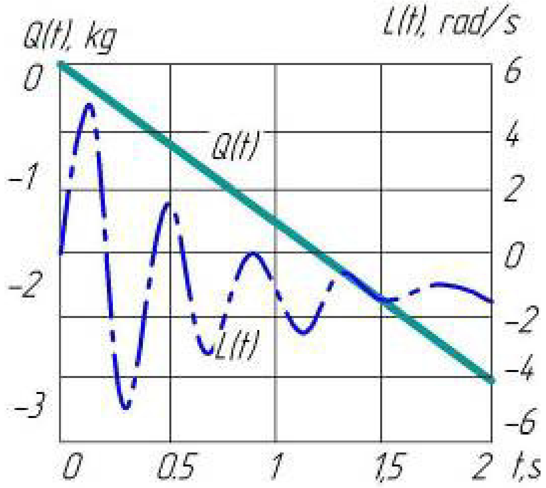

Figure 4 – Changing the angular displacement of the masses brought to the axis of rotation of the driven wheel $Q(t) = Y_k$ and their angular velocity $L(t) = Q'(t) = Y_к'$ as functions of time t

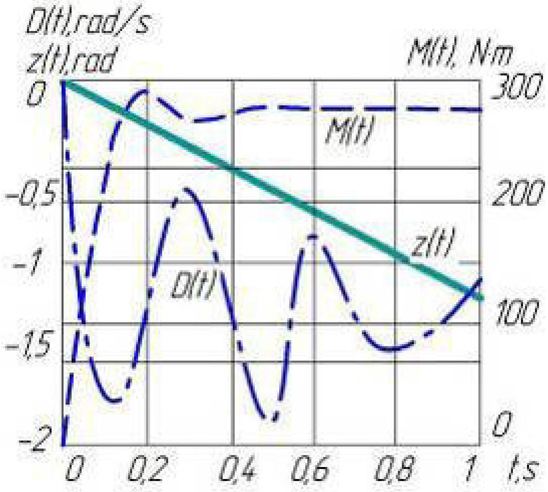

Figure 5 – Graphs of the change dependences of the angular displacement $Z(t) = Y_r$, angular velocity $D(t) = Z'(t) = Y_r'$ and the moment of the car electric motor drive $M(t)$ as functions of time t

To determine the accelerations in the system of differential equations (8) two equations of acceleration $K(t)$ of mass $Z(t) = Y_r$ and $W(t)$ of mass $Q(t) = Y_к$ are added

$$K(t) = 2.105M(t) - 31899z(t) + 31899q(t)\ ; \quad (9)$$
$$W(t) = 184780z(t) - 184780q(t) - 3351.$$

By solving the problem with the software program MathCAD, the system of equations (8) with the added equations (9), the values of accelerations change of the electric motor of the car electric motor drive $D(t)$ from time t are obtained.

As a result of the equations solutions(8 – 9), the values of acceleration of the rotor of the electric motor $K(t)$ (Figure 6) and the rotating masses of the drive $W(t)$ (Figure 7) are obtained.

According to the calculations, the built-up graph of the moment of an electric motor in the function of time (Figure 2) shows that the acceleration of the electric motor drive lasts about 0,8 seconds from the beginning of its motion. The maximum value of moment reaches at t = 0,4 s from the beginning of motion.

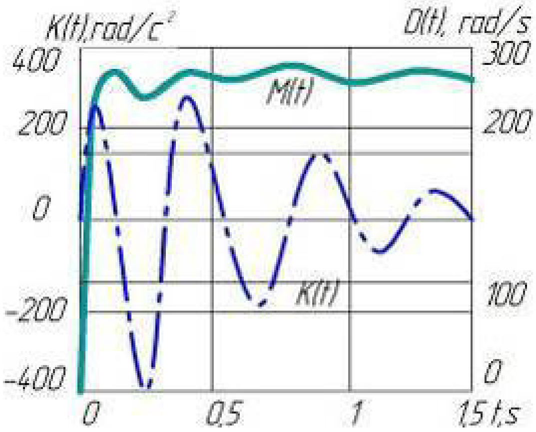

Figure 6 – Graphs of the dependences of the change of the angular acceleration of the electric motor *K(t)* rotor and the electric motor drive mechanism moment *M(t)* as functions of time *t*

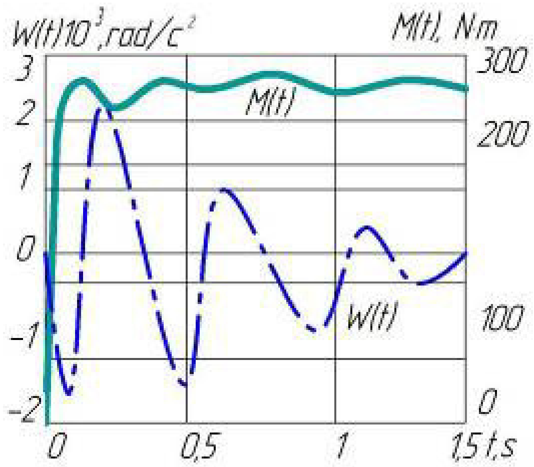

Figure 7 – Graphs of the dependences of the change of the rotating masses *W(t)* and the moment of the electric motor of the electric motor drive mechanism *M(t)* as functions of time *t*

Conclusions

1. The use of numerical methods for the integration of complex differential equations enables to use the proposed method for calculating dynamic loads in electric and mechanical systems of electric vehicles and their hybrids. In this case, the angular oscilational motion of the rotor of the electric motor becomes stable. Numerical calculations for researches of dynamics electric car on the basis of ZAZ-1102 have shown that considering the coefficient of oscillation attenuation ν almost does not affect the results of calculations.

2. The constructed graphs (Figures 2 – 7) of the dependencies of angular displacements, speeds and accelerations, the moment on the shaft of the electric motor rotor as functions of time indicate that since the car starting in its electric drive there are dynamic loads that are oscillatory in nature. By changing the moment of the electric motor and accelerating it is possible to determine the nature of the motion: constant (static) or oscillating (dynamic).

3. Graphs (Figure 2) of the dependences of the change of the masses angular displacement brought to the axis of rotation of the drive wheel Y_P=z(t) and the momentary change of the electric motor of the electric motor drive of the car M(t) as functions of time t in 0,4 s show that after the car start, the moment of the electric motor driving the electric vehicle takes the maximum value, and after 0,8 s the angular vibrational motion of the electric motor rotor becomes steady.

4. Graphs (Figure 5) of the change dependences of the angular displacement Z(t) = Yr, angular velocity D(t) = Z'(t) = Yr' and the moment of the electric motor of the car electric motor drive M(t) as functions of time t show that after 0.8 – 1.0 seconds the moment of the electric motor M(t) of the electric motor drive becomes equal to the static and the motion becomes even in character.

5. The study obtained results of the electric car drive mechanism, using the mathematical software environment MathCAD, can be used for designing, calculating and determining the dynamic loads of electric cars and their hybrids.

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