Determination method of dynamic characteristics of mobile terrestrial robotic complex manipulator

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Abstract. A method for determining the dynamic characteristics of the mobile terrestrial robotic complex manipulator is developed. A new concept for finding dynamic characteristics is proposed. It involves determining the manipulator displacement during its "quasi-rigid" movement along with the chassis along the road surface with isolated inequality through a rectangular projection. The manipulator is considered to be undeformed and its position relative to the chassis unchanged. Having considered "quasi-rigid" displacement of the manipulator, the dynamic loads acting on it are defined. At the same time, dynamic deformations of the manipulator corresponding to the "deformation" movement of the manipulator elastic system relative to its position corresponding to the "quasi-rigid" displacement are considered. Based on the proposed concept, a method for determining the dynamic characteristics of the manipulator was developed. It involves the development of a mathematical model of the manipulator when presenting it through a multi-mass dynamic system. The system of dynamics equations is presented as a structural mathematical model by means of which the dynamic characteristics of the manipulator corresponding to the robotic complex displacement along the road with a single irregularity are found. The coefficients of dynamic loads in the elastic system of the manipulator are determined by simulation.

1. Introduction.
Terrestrial robotic complexes for handling hazardous objects include a high-performance caterpillar chassis and a universal lever-type manipulator. Terrestrial robotic complexes have a limited size of about 1 m and a small mass (up to 100 kg). They are equipped with lever-type manipulators with total length of the levers is 1.5..2.5 times greater than the overall size of the complex in a whole.

Terrestrial robotic complexes move at high speeds (about 20 km / h and above). There are considerable dynamic loads. Therefore, the study of the dynamic characteristics of terrestrial robotic complexes equipped with lever-type manipulators is relevant.

The problem in general is the development of efficient mobile terrestrial robotic complexes for handling hazardous objects. The issue is related to important scientific and practical tasks that are of paramount importance for national security and defense of Ukraine.
2. Analysis of recent research and publications.
Recent research and publications have outlined a number of designs of special purpose terrestrial robotic complexes [1]. A considerable amount of research is devoted to the analysis of the geometry of complexes and the arrangement of chassis and complexes [2]. There are studies of statics of complexes [3] and studies of drive systems [4].
A considerable number of articles contain the results of studies of the kinematics of mobile robots [5]. Separate publications are devoted to studies of chassis [6] and transmissions [7].
A number of studies [8] consider the dynamics of mobile robotic complexes. The presence of complex dynamic processes is noted, their peculiarities are established [9]. Chassis dynamics issues have been considered in a number of papers [10]. Research is mainly concerned with considering the characteristics of steady-state chassis movement.
Dynamic processes in manipulators have been separately investigated [11]. The complex spatial movement of elements of mobile robot manipulators is indicated [12]. Nonlinear oscillatory processes in manipulators have been investigated [13]. The questions of dynamic accuracy of manipulators in the spatial motion of the executive body are considered [14].
Based on the analysis of information sources it is concluded that there are no methods for determining the dynamic characteristics of a mobile terrestrial robotic complex equipped with a lever-type manipulator.

3. Defining the purpose and objectives of the study.
The previously unresolved parts of the general issue include the development of a concept and method for determining the dynamic characteristics of a mobile terrestrial robotic complex equipped with a lever-type manipulator.
The purpose of the research is to develop a concept and a method for determining the dynamic characteristics of the manipulator of a mobile terrestrial robotic complex.
The objectives of the research are to develop the concept and method of analysis of dynamic processes that occur during the movement of a terrestrial robotic complex with a lever-type manipulator, and the implementation of the proposed method by mathematical modeling of the dynamic characteristics of a mobile robotic complex.
Mathematical modeling of a dynamic system of a robotic complex equipped with a lever-type manipulator with the appropriate experimental justification of the simulated dynamic processes was adopted as a methodological basis of the research.

4. The main part of the study.
The mobile terrestrial robotic complex has a caterpillar chassis on which a lever-type manipulator is mounted. To substantiate the concept and method of determining the dynamic characteristics of a mobile terrestrial robotic complex, special experimental studies have been conducted. In this case, the robotic complex moved along a horizontal surface with an isolated irregularity through a rectangular projection. The movement of the complex was recorded on video with further processing of the resulting video (Figure1).
The resulting video was processed frame by frame. The geometrical position of the individual levers of the manipulator and the chassis of the complex were recorded.

Dynamic loads of the manipulator take place during the robotic complex displacement. The smooth movements of the chassis are accompanied by moderate vibrations of the manipulator. It is reflected in the clear contours of the manipulator in the frame of the video shown in Fig. 1. When overcoming irregularities, there are significant dynamic loads on the robotic complex. At the same time intense oscillations of the manipulator are observed.

Based on the results of the analysis of the oscillations displayed on the video, the concept of determining the dynamic characteristics of a terrestrial robotic complex equipped with a lever-type manipulator is grounded. The concept is to consider separately the displacements of the manipulator during its "quasi-rigid" movement together with the chassis along the road surface with isolated irregularity through a rectangular projection. The manipulator is considered to be undeformed and its position relative to the chassis is unchanged. As a result of considering the "quasi-rigid" motion of the manipulator, the dynamic loads acting on it are determined. At the same time, dynamic deformations of the manipulator, which are small displacements corresponding to the "deformation" motion of the manipulator elastic system relative to its position corresponding to the "quasi-rigid" movement are considered.

Based on the proposed concept, a method for determining the dynamic characteristics of a mobile terrestrial robotic complex equipped with a lever-type manipulator was developed. According to this method, a dynamic model in the shape of a rigid body that performs a flat movement is applied to determine the characteristics of the "quasi-solid" movement of the robotic complex, and the manipulator is considered to be fixed rigidly to the platform. Determination of the displacements of the complex corresponding to the "quasi-solid" movement of the manipulator was carried out experimentally.

As a result of the experimental measurements, the law of the pole (point A) displacement and the law of transverse and angular displacements of the chassis through dependencies $z_A=\dot{z}_A(t)$, $\dot{\theta}=\theta(t)$ are established. The obtained laws serve as input parameters for the calculation of the "deformation" motion of the manipulator which is carried out by mathematical modeling.

A dynamic model of a robotic complex has been developed (Figure 2).
**Figure 2.** Dynamic model of "quasi-rigid" and "deformation" movement of the manipulator

The manipulator is presented through two masses $m_B$ and $m_C$ which are concentrated in the hinges B and C. The levers of the manipulator are assumed to be deformed, and the hinges are elastically dissipative with the corresponding rigidity and resistance coefficients. Controlled dampers, which create pulse dynamic loads $R_1$ and $R_2$ oriented at angles $\varphi_1$, $\varphi_2$ to the axes of the levers, are installed in the hinge units of the manipulator.

The mathematical model of the manipulator is based on the equilibrium equations of the concentrated masses.

The obtained equations in closed form describe the dynamics of the elastic-dissipative system of the manipulator during its "deformation" movement. The inputs of the dynamic manipulator system are the vertical movement of the hinge $A$ $z_A$ and the transverse and angular movements of the chassis $\theta$. Additional power inputs are the dynamic action of the dampers and the angles of forces that create the dampers $\varphi_1$ and $\varphi_2$.

The main output of the system is the vertical movement of the hinge $C$ $z_C$. Additional outputs of the dynamic manipulator system are the forces applied by the manipulator on the chassis (its vertical projection $R_A$) and the moment of reaction of the $M_A$ hinge.

A structural mathematical model of the dynamic displacements of the manipulator is found on the basis of the found dependences (Figure 3).
The model has Subsystem R_1 and Subsystem R_2 blocks which calculate projections of the forces of each damper on the axis of the lever and perpendicular axis. The Subsystem Lam C and Subsystem Lam B blocks calculate the displacement of masses in the directions of the axis of the levers, Subsystem N C and Subsystem N V blocks move the masses in perpendicular directions.

The transients in the elastic system of the manipulator are determined through the developed structural model when changing the position of the chassis (Figure 4).

Transients determine the basic dynamic parameters of the mobile terrestrial robotic complex manipulator. It is established that the displacement of the hinge C in the dynamics exceeds the static value by 50%. It gives a dynamic coefficient estimate in the limits of 1.4… 1.6.

Momentary loads in the manipulator hinges are much more intensive. Dynamic moments exceed static values by 2..3 times. There are changes in the sign of moments.
5. Conclusions
The proposed concept and method of determining dynamic characteristics of the mobile terrestrial robotic complex manipulator based on the superposition of "quasi-rigid" and "deformation" movement of the manipulator when complex displacement along the road surface with isolated irregularity is effective and provides an opportunity to find power and kinematic characteristics of the manipulator.

The dynamic coefficients of the manipulator corresponding to the kinematic characteristics are approximately twice less than the dynamics coefficients on momentary loads in the hinges of the manipulator which can reach 3 or higher.

When considering a direction for further research, it is recommended to investigate the effect of uncertain road conditions on the parameters of static and dynamic accuracy of the terrestrial robotic complex manipulator when performing special operations.

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