UDC 621.86 https://doi.org/10.23947/2541-9129-2021-2-25-32

Increasing the safety and operational efficiency of container transportation

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Introduction. Currently, there is a logistic problem in container transportation technology related to the transportation of empty freight containers, as returnable containers, since an empty container takes up as much space as a full one. A promising direction for solving this problem is the introduction of folding cargo containers. A disadvantage of this approach is the likelihood of injury to the maintenance personnel, which must be inside in the process of folding and unfolding.

Problem Statement. The objective of this study is to study the conditions for increasing the safety of preparatory work due to the design of the container, the main feature of which is the ability to realize the effect of functional self-adaptation to working conditions.

Theoretical Part. This approach allows us, when folding and unfolding, to balance the changing reactions from the own masses and the moments of its moving body parts by means of the corresponding lockable gas springs. Gas springs connect leading links and driven kinematic chains thereby ensuring that their movement in a given speed mode on the entire trajectory is independent of the speed of the driving link. For the practical implementation of the proposed design solution, the paper presents a general method for the synthesis of an adaptive controller of the container mechanisms in the process of folding and unfolding its moving parts.

Conclusion. Testing of the container showed that the effect of functional self-adaptability is quite well implemented along the entire trajectory of the container elements without the use of external lifting mechanisms.

Keywords: folding container, safety increase, self-adaptability, adaptive management.

For citation: Korotkiy A. A., Demyanov Al. An., Demyanov Al. Al. Increasing the safety and operational efficiency of container transportation; Safety of Technogenic and Natural Systems. 2021;2:25–32. https://doi.org/10.23947/2541-9129-2021-2-25-32

Introduction. Currently, there is a logistical problem in container transportation technology related to the transportation of empty containers as returnable containers. Given that an empty container takes up as much space as a loaded container, their transportation by vehicles significantly increases fuel costs, unproductive labor costs, depreciation of vehicles, traffic congestion and negative environmental impact.

Problem Statement. One of the most promising ways to solve this complex problem, which opens up the possibility of getting out of this situation, is the introduction of folding cargo containers. The folding design of the container can provide transportation of several empty assembled containers in one vehicle, allowing you to save logistics and transport costs due to more efficient organization of transportation [1].

To date, a number of design versions [2] of collapsible cargo containers-transformers are known. The main structural and kinematic features of this type of transformers are the presence of an upper and lower base, folding side and end walls. Moreover, the walls located in the end part, as well as the upper and lower bases, consist of parts attached by means of hinges to the side walls. In this case, the parts of the bases are also connected to each other by means of hinged joints. To avoid deformation of the parts of the upper base in the process of transformation, they are equipped with stops. The side walls are pivotally connected to the bases, at the corners of which there are elements for slinging. The design is based on these elements when assembled. The mounting elements are also installed on the end walls, both on the outside and on the inside.

A characteristic disadvantage of this type of construction is the need to use lifting devices for folding and unfolding, which significantly reduces their operational efficiency. In addition, a very serious disadvantage is that there is a possibility of injury to the maintenance personnel, since when performing folding and unfolding operations, such a structure requires the maintenance personnel to be inside the container.

In the current situation, the need to improve the operational efficiency of folding cargo containers is obvious. Based on the stated shortcomings, one of the directions that allow us to solve this problem is the development of an autonomous and more efficient design of a folding container. In particular, an increase in the operational efficiency of the structure can be achieved by including mechanisms that allow it to be brought into the working position and back without the use of external lifting mechanisms, thereby ensuring the safety of maintenance personnel [3].

Theoretical Part. As a solution to this problem, we propose the design of a folding container, the mechanisms of which allows us to realize the effect of functional self-adaptability (adaptation) to working conditions [2]. The implementation of this approach makes it possible, when folding and unfolding, to balance the total natural masses and moments from the moving body parts (roof, side and end walls) by means of an appropriate blocked gas spring and to ensure their movement in a given speed mode throughout the entire trajectory, regardless of the speed of the leading link. In other words, a more uniform, "smooth" speed mode is provided in relation to the leading link, which, in turn, also increases the level of safety during operation.

Let us consider the operation of such a container on the example of its use for the transportation of piece goods in the cramped conditions of urban environment. Folding cargo containers in the folded state can be stored in the warehouse in stacks, like any large-sized cargo. If necessary, with the help of a car manipulator by the spreader, the containers are slung and loaded into the body or on the platform of the car on top of each other and then secured. The manipulator with containers is sent along the route. Arriving at the loading site, for example, the yard of a residential building, the manipulator is used to unload the folded container to an empty space (Fig. 1).

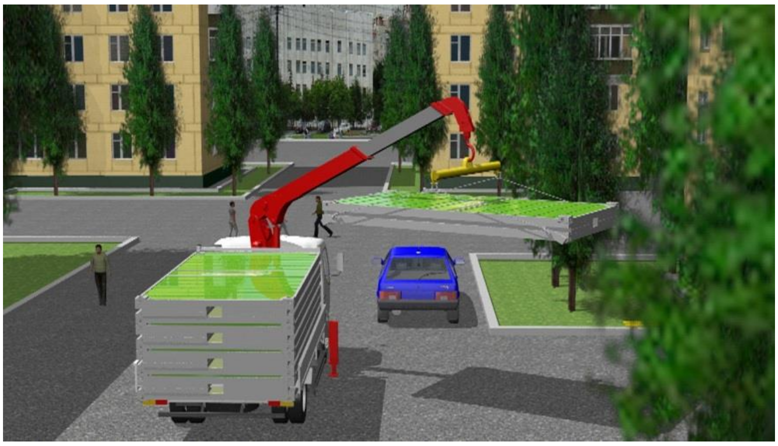

Fig. 1. Unloading of a folded collapsible cargo container

In a folded state, such a container occupies a minimum space, approximately one quarter of its volume in the opened state.

After unloading the container (Fig. 2), the operator uses the manual lever 1 through the holes 2 in the frame to unfold the side walls by engaging first with the system of levers and wings 3 of the side gas spring 4, and then with the system of levers and links 5 of the end gas spring 6. By means of the same manual lever 1, a force is created in the direction of both folding and unfolding. The generated force is necessary to press the spring-loaded buttons, which are located respectively in the end part of the rod 8 of the side lockable gas spring 4 and the end part of the rod 9 of the end lockable gas spring 6. After opening the side walls with the lever 1 through the hole 10, the end walls are similarly laid out. After the container is fully assembled, the keys to the sectional gate 11 are given to the customer, and the manipulator with the operator leaves.

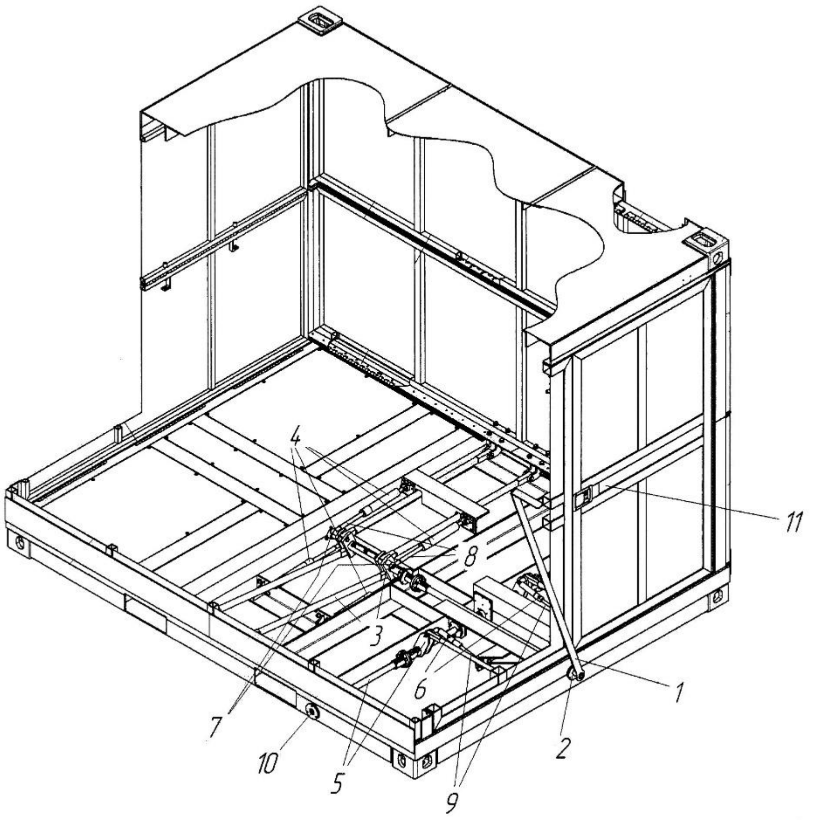

Fig. 2. Main structural components of a collapsible cargo container

After loading the container with individual cargo, the customer closes it and informs the operator about the need to move it. To do this, an empty manipulator arrives, loads the container into the body of the car and moves it to the final destination. Upon arrival, the operator uses a manipulator to remove the container from the car to the agreed place.

The customer unloads the container and informs the operator about the need to transport an empty container. The operator, in the reverse order, by means of the manual lever 1 (Fig. 3), folds the container, slings it and loads it into the car body, which moves the folded containers to the warehouse (base), where they are stacked.

Fig. 3. The process of unfolding and folding the container

Based on the description of the principle of operation of a folding cargo container, it is obvious that the main feature of such a mechanism should be the ability to balance the changing reactions from its own masses and moments of its movable body elements (roof, side and end walls) in the process of folding and unfolding. To implement such a feature, it is necessary to have an idea of the behavior of the designed mechanical system in real conditions. For ease of analysis, the systems are divided into mutable and immutable, but in real life, all systems are mutable. Their changes are caused by the laws of nature. Since this mechanical system refers to objects that have a geometric shape and mass, its adaptability will be subject to the law of least resistance [4]. This law is called the Hamilton principle, according to which the system itself chooses the option of moving from one position to another in the direction of reducing the potential energy with the least loss.

In relation to the described case, when folding and unfolding the container, there is no complete kinetostatic and dynamic picture describing the relationship and interaction of the driving forces and their moments changing in the process of folding and unfolding with the forces and moments of the resistance forces. In such cases, the change in the system control parameters is formulated directly from the control goals, for which it is most appropriate to use functional-adaptive control methods [4, 5].

Solution to this type of problem applied to adaptive systems is known as the "adaptive controller synthesis" procedure. To build an adaptive controller of a node, it is necessary to determine the parameters in the form of "input-output" [6].

From the description of the design and operation of the container mechanisms, it follows that their power and speed characteristics change during the opening process and, therefore, the algorithm of operation of such a controller will have to adapt to the changing parameters of the object during its operation.

Let us consider in general the process of constructing adaptive mechanical systems using the equation of the control vector of perturbed (real) motion for subsequent application to the leading and driven kinematic chains of the container [7, 8]:

$$\dot{X} = \phi(x, u, t) \tag{1}$$

where (t)— n - dimensional vector of variable states of the object; $u(t)$— m- dimensional vector of control; t — the time of the operation of the object.

Let us present equation (1) in the expanded form:

$$\frac{dx}{dt} = \phi_i(x_1, ..., x_n,\ u_1 ... u_m,\ t),\ (i = 1,\ n) \tag{2}$$

where $\varphi_i(x_1,...,x_n,\ u_1...u_m,\ t)\cdot(i=1,\ n)$ — the given functions that are assumed to be continuous and differentiable by the required number of times $x_1,...,x_n,\ u_1...u_m,\ t$.

In the original equation (1), both the control parameters and the object state parameters are the functions, the nature of change of which over time is unknown, but can be determined from the following conditions. The initial ($x^{(0)}$) and final ($x^{(1)}$)states of the object (1) are set:

$$x(t_0)=x^{(0)} \tag{3}$$

$$x(t_1)=x^{(1)} \tag{4}$$

where t_0 — the time of the beginning of the operation of the object; t_1 — the time of the end of the operation of the object.

The control efficiency is estimated using the integral:

$$\gamma=\int_{t_0}^{t_1}\phi_0(x,\ u,\ t)dt\ , \tag{5}$$

where $\varphi_0(x,\ u,\ t)dt$ — the given continuous function of its arguments.

When solving this problem, we take a decrease in the value of this integral as an increase in the efficiency of control. Next, we take into account the restrictions on the parameter of the state and control variables, and then express through these restrictions the permissible limits of the control resource and the permissible limits of changing the state variables:

$$|u_k(t)|\le u_k^*\ (k=1,\ m)\ , \tag{6}$$

where $u_k^*(k=1,\ m)$ — the specified numbers.

Taking into account the kinematic and design features of the container mechanisms (control objects) and the operating conditions (state variables) in the described case, we define a bounded set u in the space of variables $u_1,...u_m$. Since the container mechanisms work in a closed loop, we can assume that this variable domain is a closed set. The control is possible inside and at the border, that is $u_1(t)=u_1^*$.

At the stage of circuit synthesis under conditions of information scarcity, the equations of theoretical (unperturbed) motion are used to describe the kinematics of the elements of mechanical systems. However, already at the design, manufacturing and testing stages, there will be some deviations from the design conditions, i.e. the actual movements of the elements of the folding container will differ from the theoretical ones. To account for these deviations, it is customary to use perturbation equations, the structure of which includes a parameter that takes these deviations into account.

Let the kinematic scheme be found, and the equation of theoretical motion is drawn up. Hence, the function $u^*(t)=u_k^{(0)}(t)\ (k=1,\ m)$ is known. Solving equation (1) taking into account the value of this function and the constraints (3), (4) we obtain $x_i^*(t)\ (i=1,\ n)$. Then the equation that will describe the real motion of the elements of the projected system can be obtained by entering the perturbation (deviation) function

If $\delta_{xi}(t)\ (i=1,\ n)$ and $\delta_{uk}(t)\ \ (k=1,m)$ — the deviations of the real motion and control from the theoretical one, then the perturbed motion of the system is described by the functions:

$$x_i(t)=x_i^*(t)+\delta_{xi}(t)u_k(t)=u_k^*(t)+\delta_{uk}(t)\cdot(i=1,n;k=1,m) \tag{7}$$

According to the theory of adaptive control, the numerical values of deviations $\delta_{xi}(t)$ $(i=1,\ n)$ are unknown and are random small quantities. In this case, their range should not exceed a certain specified number, i.e., satisfy an inequality of the form:

$$\sum_{i=1}^{n}\delta_{xi}^{2}(t_0)\le\varepsilon^{2} \tag{8}$$

Next, for the perturbed motion of the system (5), we express the control efficiency as a function of variable states:

$$\gamma=\int_{t_0}^{t_1}\left[x_i(t)+u_k(t)\right]\cdot dt=\int_{t_0}^{t_1}\left\{\left[x_i^{*}(t)+\delta x_i(t)\right]+\left[u_k^{*}(t)+\delta u_k(t)\right]\right\}\cdot dt \tag{9}$$

So, the solution to the problem can be reduced to minimizing the functional (5) in a given interval $(t_1,\ t_0)$ i.e.:

$$\gamma=\lim_{t_1\to\max}\frac{1}{t_1-t_0}\times\int_{t_0}^{t_1}\left\{\left[x_i^{*}(t)+\delta x_i(t)\right]+\left[u_k^{*}(t)+\delta u_k(t)\right]\right\}\cdot dt \tag{10}$$

One of the approaches to solving the problems of analytical design (synthesis) of the controller is to determine the matrix ***c*** of numbers with the dimension $m\times n$ of the controller equation, which in the first approximation can be described by the equation in matrix form:

$$u=c\cdot x \tag{11}$$

where c — the matrix of numbers; x — the movement of the object.

The implementation of this approach makes it possible to ensure the stable movement of the control object in case of disturbed motion.

Let us consider the control and state parameters as functions of the control and state variables for the case when they do not depend on the initial conditions from some set (7), which have the following form:

$$x_i^{*}(t)+\delta x_i(t)=\phi_1\cdot[(x_1...x_i),(\delta x_1...\delta x_i)] \tag{12}$$

$$u_k^{*}(t)+\delta u_k(t)=\phi_2\cdot[(u_1...u_k),(\delta u_1...\delta u_k)] \tag{13}$$

Thus, the container mechanism control function includes parameters for which the constraints are known, but their current values are not known. However, the structure of adaptive systems implies the possibility of forming a function that contains a criterion for changing these parameters:

$$\beta(t)=\phi_3(\beta,\ u) \tag{14}$$

where $\beta(t)$ — the adapter, i.e. the system element implementing the adaptation mechanism.

So, the algorithm of the controller operation is described by equations (12), (13), and the algorithm of the adaptation process is described by equation (14) containing the adapter. In the considered version of the design of the folding container, the adapter with a given load F_n and speed V_n parameter that determines the control resource will be a gas spring, and the parameters of control and the state of the object, respectively, the load-speed characteristics of the leading link F_0, V_0 (lifting mechanism) and the driven kinematic circuits F_i, V_i.

$$\beta(t)=\phi_3(F_n,C_n)\quad u(t)=\phi_2(F_0,V_0)\quad x(t)=\phi_1(F_i,V_i) \tag{15}$$

Operational tests. To check the operability of the proposed design of the folding cargo container, the tests of the prototype mechanisms were carried out. The development of technical documentation, production and testing of the prototype was carried out in OOO IKTS "Mysl".

The test of the container mechanisms showed their operability, namely, the ability of such a structure to balance the own weights of the roof, side and end walls, including the sectional doors, during the folding and unfolding process, due to the use of lockable gas springs.

The use of gas springs as an adapter allows you to realize the effect of functional self-adaptability to the operating conditions of both the control parameters and the parameters of the object state. Moreover, the effect is quite well realized along the entire trajectory of the container elements without the use of external lifting mechanisms.

Conclusion. The proposed approach to improving the design of a collapsible container will allow us to more effectively solve the logistics problems of transportation in an urban environment by:

— improving the safety of people during preparatory operations;

— reduction of fuel costs by reducing the speed of transport;

— reduction of congestion on urban roads;

— reduction of the environmental burden.

For the practical implementation of the proposed design solution, the method of synthesis of the adaptive controller of the folding-unfolding process of the container mechanisms is presented in a general form.

In addition, as tests have shown, the use of gas lockable springs as connecting elements between the driving links and the driven kinematic chains ensured the normal functioning of the object without the use of external, not related directly mechanisms.

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Submitted 22.03.2021

Scheduled in the issue 30.04.2021

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Contribution of the authors:

A. A. Korotkiy — the main idea of the project, justification of the influencing factors, development of the general research program; Aleksandr A. Demyanov — development of questions of the theoretical part; Aleksey A. Demyanov — analysis of the results of the study, formulation of directions for improving the design, design of the text of the article.