DESIGN OF ADAPTIVE SUSPENSION FOR UNIVERSAL VEHICLE COURSE

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ABSTRACT

The article refers to the modernization of the adaptive frame of the vehicle, designed to automatically control the movement of the vehicle on a solid surface. As everybody knows, motor vehicles play a substantial function in the economies of many cities, states, and countries, providing useful tools of carrying people and goods. These vehicles can also have considerable impacts on reliability, infrastructure and the surroundings. The suspension construction affects the vehicle's productivity in terms of drive, infrastructure damage, suspension workspace, power and rollover resistance, yaw resistance, braking, and so on. The given research paper discusses the types and methods of applying adaptive suspensions. The proposed model makes it possible to use these vehicles for driving in various road conditions - mountainous terrain with a slope of more than 35°, steppe off-road terrain with frontal obstacles up to half the length of the wheel radius, while existing control schemes and prospects for their further development can be improved and intelligent transport systems implemented.

Keywords: adaptive frame, transportation, universal vehicle course, suspension, suspension design, road vehicles.

1. INTRODUCTION

Improving the quality, reducing the time and cost of road construction are inextricably linked to the problems of efficient use of transport vehicles [1]. Currently, the automatic control system of the transports has not yet received widespread distribution. One of the reasons for this is the differences in the machine control methods used by the human operator and automatic controls [2].

Traditional approaches to automatic control involve pre-setting the parameters of the controller and the control algorithm, which do not change during the working passes. The human operator, even without numerical data on the indicators of the workflow, adjusts the algorithm of manual control of the vehicle to changing conditions. Improving the efficiency of automatic workflow management is possible by creating adaptive control systems, the parameters of which are automatically adjusted to changing workflow conditions and machine dynamics [3-4].

The development of automatic control systems should be based on information about the dynamics of vehicle work processes. To study management processes, it is necessary to develop two approaches to workflow modeling. The first one is aimed at developing analytical models of workflow elements and combining them into a common simulation model [5]. This approach is based on a priori information about the design, allows you to conduct computational experiments in the synthesis of new management systems. The second approach to vehicle workflow modeling is based on workflow identification, which allows you to create adaptive dynamic models based on experimentally measured workflow parameters [6]. This approach makes it possible to find and model hidden dependencies between workflow parameters without having complete information about the device and environment characteristics [7].

In this article, adaptive situational control of a platform with a transformable frame is proposed when overcoming an arbitrary sequence of obstacles such as a ditch and a cliff with a priori unknown dimensions. When building an adaptive frame, we considered two group of necessary conditions: First of them are the problems of smoothness of the vehicle, speed, and minimization of dynamic loads acting on the cargo, components, passengers, and drivers of the vehicle. As well as the requirements for handling, safety, stability, vehicle stabilization, and body stabilization were chosen as the second requirements group [8]. To justify the efficiency and effectiveness of the proposed structural and algorithmic solutions, calculations of the dynamics of Autonomous controlled movement of the platform model are performed.

2. LITERATURE REVIEW

The problem of control in conditions of incompleteness and inaccuracy of the description of object models and conditions of their functioning is one of the classic problems of building automatic control systems. The application of adaptation principles to this task has attracted the attention of scientists and designers for many decades.

Currently, research in this area is carried out with relentless intensity, its scope covers new and complex (nonlinear, non-stationary) systems and offers more advanced adaptive control algorithms.

Adaptive control is based on the idea of modifying the control algorithm in real time when the parameters that determine the dynamics of the object are only partially known or change over time. In accordance with this concept, a large number of adaptive management methods have been developed [9-13]. Some of them are based on parameter estimation in order to configure control algorithms and assume rather slow changes in these parameters over time, so the separation principle is valid. Here we can highlight the results for linear systems with variable parameters and a configurable gain [14].

Other strategies use the passivity property to perform direct adjustment of the regulator's gain via a differential equation. The strategy of adaptive control based on passification was proposed in 1974 for linear systems and then extended to nonlinear systems. Since this strategy does not require parameter estimation, and the number of configurable parameters is small even for high-order objects, it is also sometimes called simple adaptive control [15].

The tasks that most intensively stimulate research in the field of adaptive control include the task of controlling Autonomous robotic systems. Very active research is being conducted in the field of application of adaptation methods in remote control systems for Autonomous mobile robotic objects. They have found all sorts of applications in such areas as space research, underwater work and remote surgery [16-19]. A number of reviews and a large number of publications are devoted to remote control [20]. As noted in [21], the main problems inherent in such systems can be divided into the following categories: uncertainty of the operator model [22]; uncertainty of the master system model (internal perturbation); delay in the communication channel; uncertainty of the slave system model (internal perturbation) [23]; uncertainty of the environment model influence of external unknown perturbations. These factors can significantly reduce the quality of remote control systems and even lead to loss of their stability [24-25].

3. PROBLEMS AND METHDOS IN DEVELOPING OF ADAPTIVE FRAME

Improving the smoothness of the ride and protection from vibrations is an urgent problem of transport engineering. Increasing speeds, increasing the maximum load capacity and mobility of vehicles, increasing the working time of drivers, and often unsatisfactory road conditions make it necessary to improve vibration protection systems and introduce new technical solutions.

One of the ways to solve the problem of reducing costs and reducing time for the development of new vehicles and control systems is to use computer simulation. At the same time, the use of special software for building mathematical models with control contours reduces the development time both at the stage of creating mathematical models and at the stage of implementing control algorithms in the microprocessor unit of the car's control system.

The analysis of algorithms for controlling suspension parameters showed that they have a complex structure and their implementation requires complex control systems. Creating and debugging such control systems is a complex and resource-intensive task. Mathematical modeling of the entire system with control loops and control blocks can significantly reduce economic costs both at the design stage and at the testing and debugging stage. It also allows you to conduct further research without creating prototypes.

As a result, one of the main problems for operator-oriented adaptive controllers is modeling its behavior. Usually, the dynamics of a human operator is described by a passive system "load-spring–damper", which is subject to external influence [26]. Control of robotic systems in the presence of constraints raises a number of difficult problems. Accurate modeling of these processes requires the ability to solve dynamic equations for calculating the system's movements when contacts occur. In [27], it is noted that consideration of the physical limitations imposed by dynamic interaction shows that position control is not sufficient for remote control of the manipulator, but it is necessary to control the force or the position–force combination.

One of the most common control methods for problems with constraints is impedance control [28]. Since the manipulator is mechanically connected to the affected object when contact occurs, it cannot be considered as an isolated system. In [29], methods are presented that lead to a unified approach to motion control under kinematic constraints, dynamic interaction between the manipulator and the environment, achieving the target position and avoiding obstacles. The "impedance control" proposed in [30] is implemented by calculating the control force from the difference between the desired and actual positions of the manipulator, along with its first and second derivatives.

Adaptive environmental - oriented controllers improve the reliability and quality of the remote control system by evaluating and enabling the parameters of the environment model to form the control.

4. DESIGN OF ADAPTIVE UNIVERSAL VEHICLE SUSPENSION

Research of the structure of adaptable mechanisms of the chassis is carried out by the research laboratory of the department "Transport engineering, mechanical engineering and standardization" of the Kazakh University of Railway Transport.

One of the adaptive mechanisms of the chassis is a parallelogram mechanism that serves as a component frame of the chassis.

Figure-1 shows the kinematical scheme of the adaptive self-propelled chassis which consists of: two half-frames 1 and 2 on which two transverse bars 3 and 4 of the same length are hinged on the end sides, forming the half-frames 1 and 2 with the upper part of parallelograms "abcd", and four supporting walking wheels - 5, 6, 7 and 8 hingedly installed in the lower part of the half-frames 1 and 2. In order to ensure that both frames 1 and 2 are always maintained in an upright position, irrespective of the gradient of the road surface, the bodywork 9 is hinged on the middle part of the transverse bars 3 and 4, where the mass G of the vehicle is concentrated.

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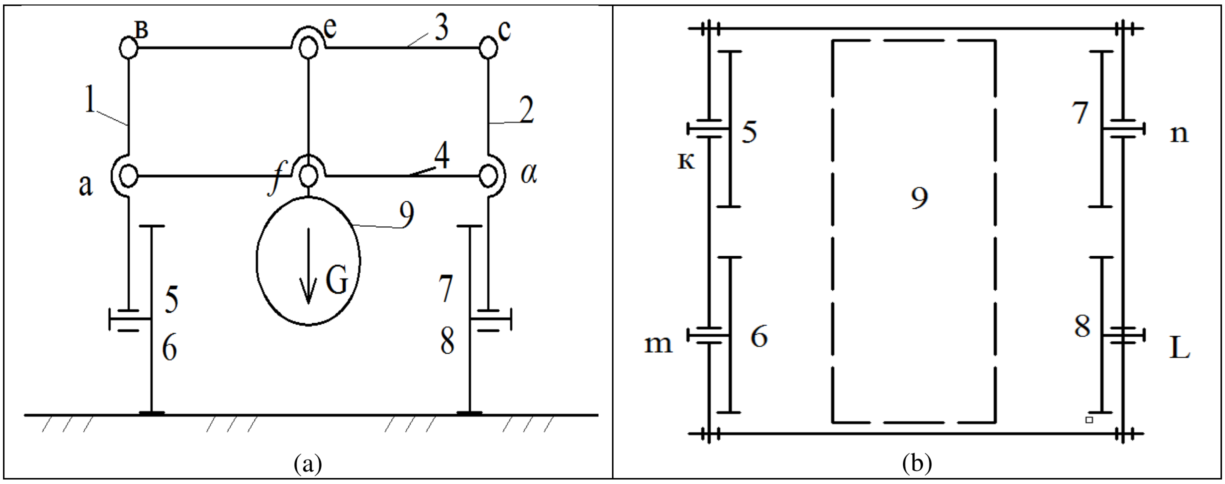

Figure-1. The kinematic diagram of the chassis mechanism.

The installed ef rod on the middle part of bars 3 and 4 is rigidly connected to the body 9. Therefore, it is the heaviest part of the chassis.

When driving on the uneven surface of the road in Figure-2 the chassis mechanism is controlled by the massive element 9 together with the ef rod, because the massive body part always remains in upright position. As a result, the direction of the weight force vector G will not be able to leave the support pad tt-t′ t′, formed by four support wheels, eliminating the rollover chassis with large gradients of a reference platform.

This property of the chassis mechanism is similar to the principle of preserving the stability of the body of mountain goats on steep rocks. Then the anatomical structure of the chassis mechanism should be believable. The scheme of the chassis mechanism (Figure-1. and Figure-2.) consists of eight solid elements (links) - half-frames 1 and 2, walking wheels 5, 6, 7 and 8 and cross bars 3 and 4, so the number of links-8.

These elements are interconnected by 8 single-movable hinges (a,b,c,d,k,n,m,L) (single-movable kinematic pairs).

Therefore, the number P_1= 8. Four support-walking wheels (5, 6, 7 and 8) form five movable kinematic pairs -P_5 with the road surface. So P_5=4 Then the total number of chassis mechanism mobility is equal to:

$$W=6n-5p_1-p_5=6\cdot 8-5\cdot 8-4=4, \quad (1)$$

Two hinges e and f are the elements of passive coupling - the ef rod. Therefore, they are excluded. These mobility of chassis mechanism W=4 must be controlled by four external devices. Otherwise, the mechanism will have either excessive mobility or superfluous communication. In both cases the mechanism will definitely not work.

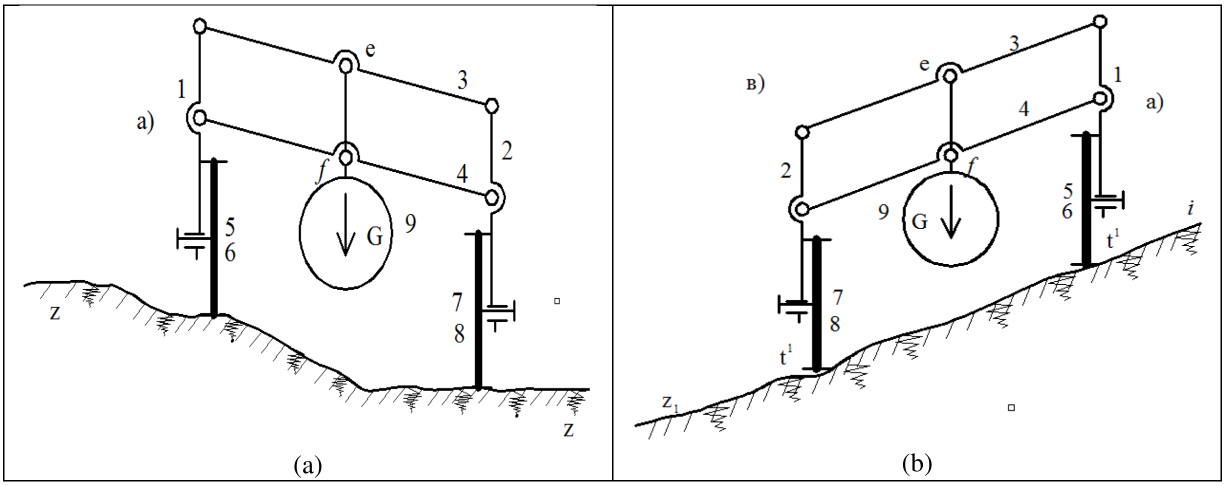

Figure-2. The scheme of adaptation.

The work of a new design of the adaptive frame of vehicles with a universal stroke (Figure-3), which consists of three nodes - the mechanisms of the rear and front axles and the spar chain, is outlined below.

Figure-4 shows the general kinematic diagram, consisting of two wheels 1 and 2, freely rotating on the axles of the hubs 3 and 4, made in the form of lateral sides of the AVSD parallelogram, and two transverse sides 5, 6 are parallel to the axes of the hubs, passive connection 7, made in the form of an additional lateral side of the EP parallelogram. The scheme of the rear axle mechanism (Figure-4) is mounted on a horizontal supporting surface xx).

Now let's see how the anatomy of the mechanism scheme is formed by the formula of Somov - Malyshev. The number of moving links n=6, the additional side of the EP parallelogram is considered a passive element of the scheme.

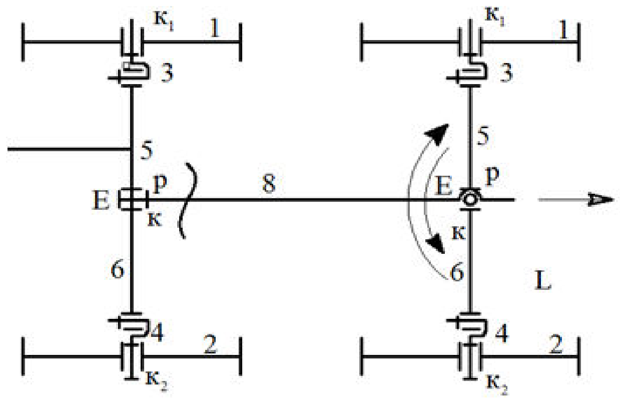

Figure-3. The General scheme of the adaptive frame.

Therefore, the number of links and kinematic pairs of this link are not taken into account. And the number of single motion kinematic pairs P_1 (A, B, C, D, K_1, K_2), is also equal to six, i.e., P 1=6. Reference points O1 and O2 are pairs P5=2. Then:

W_1=6n- 〖5P〗_1- P_5=6·6-5·6-2=4, (2)

where, one mobility scheme is a rectilinear motion along the longitudinal axis (perpendicular to the plane of the scheme), and the other - rotation of the parallelogram scheme ABCD around the K_1K_2 axis, the third mobility is the rotation of the rear axle around the reference point O1 or O2 relative to the vertical axis, the coordinates and the fourth mobility is the rotation of the parallelogram ABCD scheme together with the wheel 2 relative to the AB side (thin lines).

To eliminate the mobility of the circuit with respect to two point's O1 и O2, we install elastic suspensions S1 and S2 in the form of two springs. On ends of these springs S1 and S2 we connect at the point K, and connect the other ends with the hinges B and D of the parallelogram ABCD.

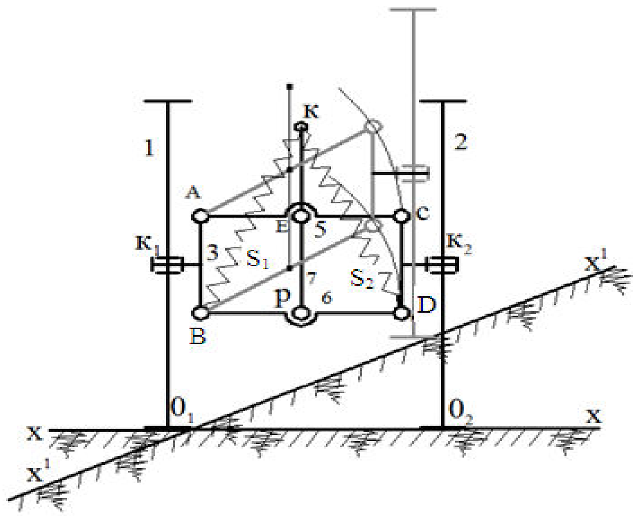

Figure-4. Diagram of the rear axle mechanism.

Figure-3 shows the general scheme of the adaptive frame of vehicles, which consists of a rear axle mechanism that has four mobility relative to the road surface, of the front axle which is identical in construction with the rear axle and of the spar chain 8 connecting the rear axle to the front axle through passive elements (passive connections) EP. Moreover, one end of the spar 8 is connected to the front axle mechanism with the help of a single-movable hinge L, which ensures relative rotation of the rear and front axles.

Then, the total mobility of the adaptive frame of the vehicle is determined by taking into account all the links of the general scheme.

The number of moving links of two axels is n = 12, since the number of links of the rear axle 6 and the front axle 6, and the number of single-motion kinematic pairs P_1=13,, since for the relative rotation of two axels a single-movable hinge L was introduced, so the sum of the single-movable hinges of two identical axels will be:

P_1=6+7=13, (3)

The spar, as noted above, is a passive element of the scheme. The total mobility of the frame is:

W_3=6·n-5p_1·p_5=6·12-5·13-4=72-65-4=3, (4)

For unambiguous operation of the mechanism, circuit of the frame an independent drive on each mobility must be installed.

In Figure-5, the chassis scheme on four supports (with walking wheels) with a parallelogram type acefbd composite frame on a flat supporting surface (Figure-5a.) is shown and on an inclined supporting surface (Figure-5b). Adding to the device a parallelogram mechanism of the passive element efc with a load G gives a special property to control the positions of the side half-frames ac and bd. Since the main mass of the chassis is placed on the passive element ef, it controls the positions of the half-frames, keeping them strictly in the vertical position

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regardless of the unevenness of the supporting surface. Such a composite frame is called an adaptive chassis frame with a parallelogram effect.

If this scheme turn into a rigid frame, considering that all joints acefbd do not exist the scheme becomes a frame of the known vehicles (Figure-6), where it is fair:

G=2·R;{$M_1 = G \cdot cf M_2 = G \cdot fd$, (5)

Where: cf=fd ;$M_1 = M_2$; $R = R_1 + R_2$; $R_1 = R_2$.

This is the equilibrium condition of a static system. If this system put on an inclined plane OX', then (in Figure-3. shown by dashed lines) the stability corresponds to the following ratio of the above parameters:

G≠2·R; $R_1 \neq R_2$; $M_2 = G \cdot fc$; $M_1 = 0$., (6)

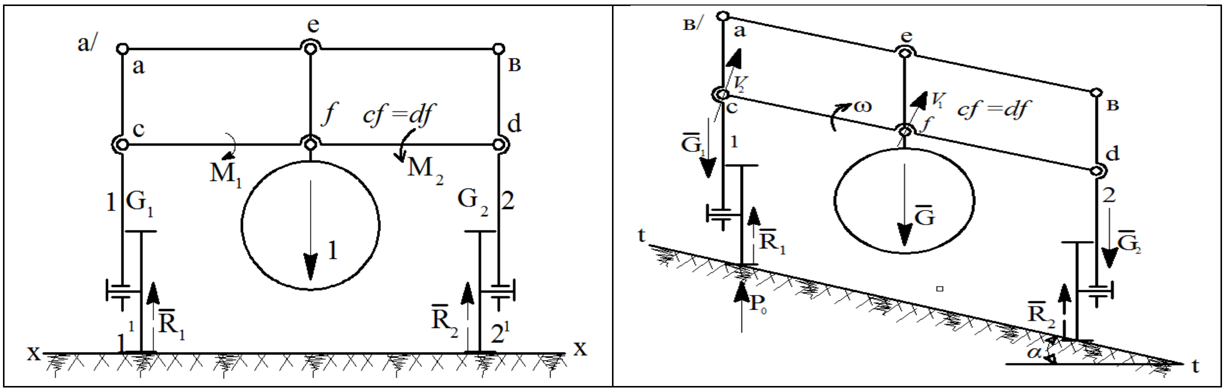

Figure-5. Scheme adaptive chassis of the vehicle.

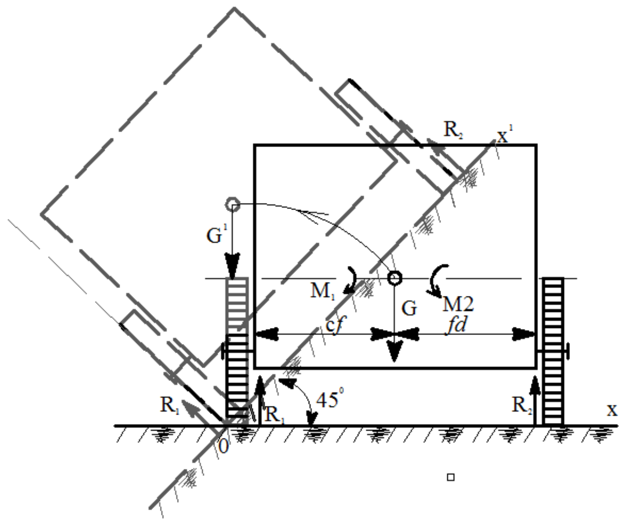

Figure-6. The critical situation of four-wheeled transport.

This means a stable balance is disturbed. The chassis mechanism rotates relative to the left o-O reference line, i.e. overturns. This change of stability was due to a change in the relative position of the force vectors - $R_1 \rightarrow$ $R_2 \rightarrow$ $G \rightarrow$

Now that you rotated the frame install hinges acefbd at the parallelogram diagram (Figure-5A.) and put the chassis on an inclined plane on the scheme of the mechanism (Figure-5b). In this case, the parallelism of the acting external forces and reactions in the supports will not change. The action of the support surface in the form of a force P_0, is distributed over the hinges (Figure-5b.), i.e.

N=P_0·V_0=G_1·V_2=G·V_1, (7)

Where: P_0 —-action of the support surface on the chassis mechanism (H);

V_0 − is the speed of a fulcrum O (c); $G_1 = \frac{G}{2}$G/2– weight of the first half frame (H); V_1 − velocity of the hinge centre - f; V_2 − velocity of the hinge centre – c;

G- Weight of a composite frame (H); N- power (energy) $\left(\frac{\text{Н·м}}{\text{с}}\right)$;

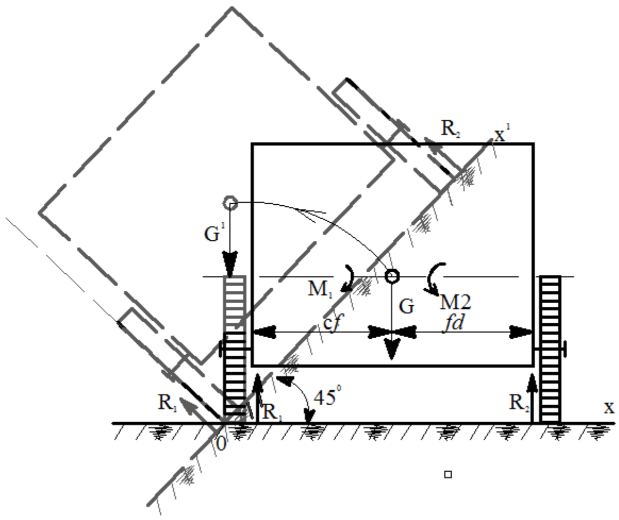

Figure-7. Adaptation scheme when driving on an inclined plane.

The speed of the point "d" is equal to zero, because when the parallelogram mechanism is rotated by the force P_0, the right semi-frame is motionless, i.e. $V_d = 0$ and therefore

$$G_2 \cdot V_d = N = 0 \quad (8)$$

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Speed: $V_2 = \omega \cdot \mathrm{cd(c)}$;
$V_1 = \omega \cdot \mathrm{cf(c)}$;

That's why: $V_2 = 2 \cdot V_1$, as well as $G = 2 \cdot G_1$, on this reason $R_1 = G_1$ и $R_2 = G_2$. The reactions in the supports are the same.

As a result, it can be determined that the adaptive frame is able to adapt to the unevenness of the support surface, i.e. maintain a stable balance of the frame when driving in mountainous terrain (Figure-7).

Let's consider the critical position of the chassis mechanism at the moment of overturning, when the angle of inclination of the supporting surface is $\alpha = 45^{\circ}$. Longitudinal stability (Figure-8):

$$tg\ \alpha = \frac{2 \cdot h}{L_0} = 1. \text{ From there: } L_0 = 2 \cdot h = 4 \cdot r \quad (9)$$

Transverse stability: $tg\ \beta = \frac{2 \cdot h}{B_0} = 1$. From there: $B_0 = 2 \cdot h$.

When designing chassis mechanism schemes are set by valid values [L] and [B], which are equal to:

$$[L] = K_1 \cdot L_0 \text{ and } [B] = K_2 \cdot B_0 \quad (10)$$

The coefficients are $K_1 \geq 1.5$ и $K_2 \geq 2$.

To adapt the chassis, the value of the coefficient K_2 does not make sense, because there is no critical position for this type of chassis.

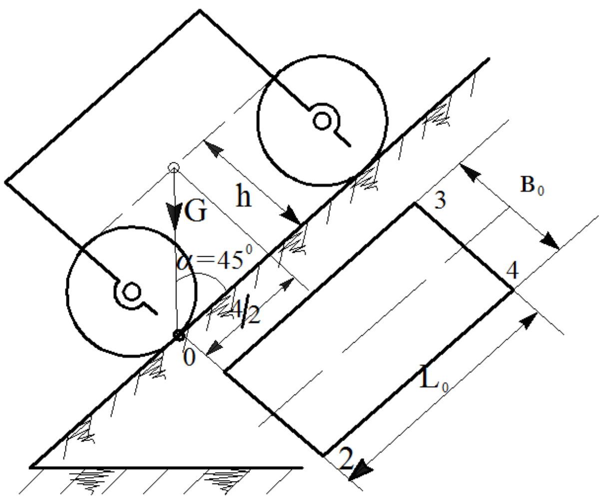

Figure-8. Dimension calculation scheme.

5. DISCUSSION

Approaches to solving the problem of controlling wheeled and tracked devices with transformable suspensions/frames are widely presented in the literature. In [31], we consider the problem of controlling the morphology of tracked platforms with active track levers based on incomplete data about the environment. In [32], we studied an approach to building a system for Autonomous detection and overcoming obstacles such as stairs with a tracked platform using elements of fuzzy logic. The article [33] describes the stages of development of a wheeled crawler robot with a variable track profile and considers algorithms for overcoming escarpments with such a device. In [34-35], approaches to situational planning of a six-wheeled platform behavior strategy when moving in an environment with obstacles are considered. The proposed approaches use sensor readings of the active suspension configuration and information about the presence of contact between the motor wheels and the underlying surface as information on the basis of which all the necessary calculations are made.

When developing a vehicle system design, designers have to solve the problem of matching the following two groups of conflicting requirements: 1) requirements for comfort, a high level of smoothness of the vehicle, isolation of the body from vibrations and road noise caused by hard rolling tires and negatively affecting equipment and people; 2) requirements for traffic safety, handling and stability of the vehicle.

Currently existing adaptive and active vehicle suspensions have a number of disadvantages, which are discussed in detail in this paper. In particular, we can note the limited range of regulation of their performance characteristics [36], high cost [37], significant heating of elements during operation.

The development of computer technology, methods for making mathematical models, numerical integration of differential equations, and optimization make it one of the most important tasks at present to develop mathematical models that allow us to fully and accurately convey the dynamic properties of the system.

6. CONCLUSIONS

The paper conciders the types and uses of adaptive frame of modern vehicles, the feasibility of their use for various vehicles, such as modern cars, tractors and other ground-based tractors, which allows these vehicles to drive under different road surface conditions -mountain terrains with a slope of more than 35^0, steppe off-road conditions with frontal obstacles up to half the length of the wheel radius. The existing management schemes and prospects for their further development can be improved and intelligent transport systems can be implemented.

Testing of the proposed frame has shown its effectiveness when the platform overcomes ledges of various heights, descends from relatively high ledges and crosses ditches. The inclusion of the algorithm in the platform motion control system allows overcoming obstacles with a small dynamic coefficient of friction between the support surfaces and the wheels of the device.

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