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Improvement of warehouse hovercraft transport devices with inclined feed channels

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Introduction. The paper considers the question of the directions of mechanization and automation of rack warehouses logistics. The paper considers hovercraft transport devices operating in the storage area with inclined feeding channels. The displacement of the load center relative to the geometric center of the support surface is studied. It is noted how this affects the main characteristics of the studied devices.

Problem Statement. Previous studies have proved the sufficient performance of non-powered hovercraft transport devices with inclined feed channels, their safety and efficiency in the transportation of piece goods, as well as the potential for mechanization and automation of transport and storage operations in rack warehouses. The task of this work is to present a scheme of mechanization for the storage area of a rack warehouse equipped with a transport device with inclined feeding channels.

Theoretical Part. In rack warehouses designed for the storage of individual goods, the receiving, storing and sending operations are in most cases carried out using carrying and lifting machines. Stacker cranes are most common, but their use requires the creation of complex and expensive systems, i.e. significant capital and operating costs. The article considers the system of mechanization of a rack warehouse with the use of hovercraft vehicles with an off-center location of the cargo. In this case, the height of the airbag depends on the eccentricity of the load location. The points of application and the values of the resistance and traction forces, torques and friction forces that affect the total resistance are shown, which are typical for such a situation

Conclusion. The results of the research allow us to state that in some cases, instead of traditional transport devices, the use of hovercraft transport devices with the inclined feed channels is effective in logistics enterprises.

Keywords: air bag, rack warehouses, load center, load conveyor.

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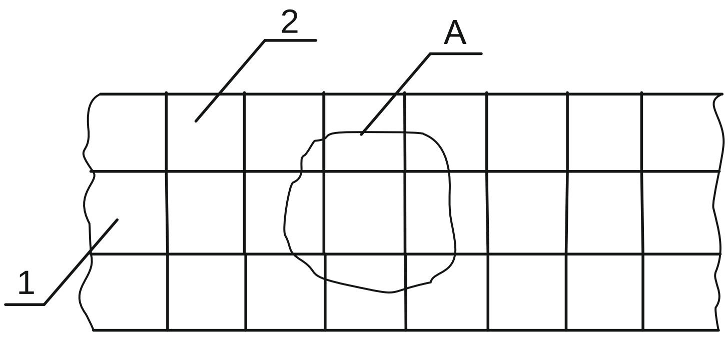
Introduction. Storage-retrieval work in rack warehouses can be successfully mechanized with the help of non-powered hovercraft transport devices with inclined feed channels. Their sufficient operability, safety and efficiency in the transportation of piece goods have been proven. The authors of [1-4] assumed the same height of the air cushion at all points between the bearing surface of the transport device and the supporting surface of the load. However, this is only possible if the gravity center of the load is located above the geometric center of the support surface, so this approach can only be considered as a special case. Thus, the application of the methods presented in [1-4] for determining the main parameters of transport devices with a significant shift in the gravity center can lead to the creation of an inoperative structure.

Problem Statement. The task of this work is to present a scheme of mechanization for the storage area of a rack warehouse equipped with a transport device with inclined feed channels. In this case, it will be established how the displacement of the gravity center of the load relative to the geometric center of the support surface affects the main characteristics of the devices under consideration.

Theoretical Part. Figure 1 shows the scheme of mechanization of the rack warehouse. [5]



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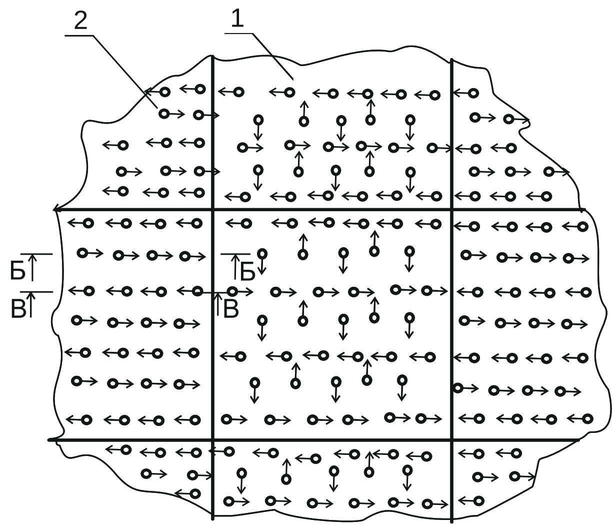

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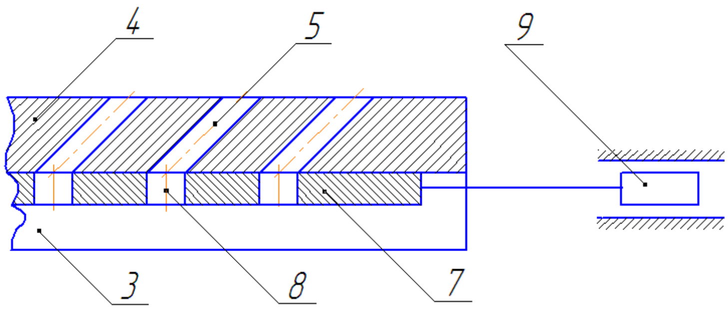

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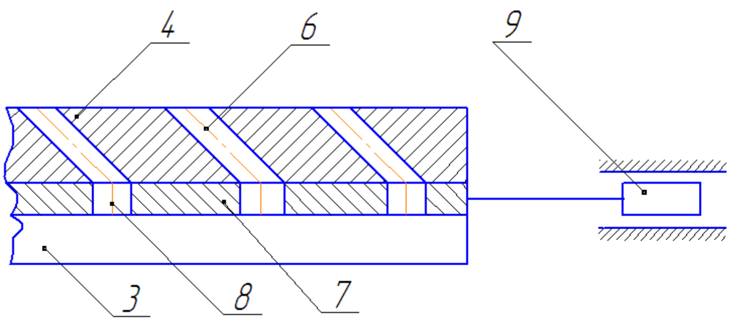

d)

Fig. 1. Scheme of mechanization of a rack warehouse using hovercraft transport devices: top view (a), view A (b); section B — B (c); section B — B (d); 1 — transport conveyor; 2 — rack cell; 3 — receiver chamber; 4 — bearing plate; 5, 6, 8 — feed channels; 7 — control plate; 9 — control device

The floor of the cargo storage rack is:

— longitudinal transport conveyor 1 with air cushion,

— cell 2.

The cell consists of:

— receiver chamber 3,

— bearing plate 4 (its feed channels tilt in both directions),

— control plate 7 with vertical feed channels 8.

The control plate is driven by the device 9 (pneumatic cylinder, solenoid, electromagnet, etc.).

When releasing a pallet with a load from the cell 2 of the rack, the control plate 7 is installed using the device 9 in such a position that the supply channels 5 are open and the channels 6 are closed. The air, which is under pressure in the receiver chamber 3, enters through the supply channels 8 and 5 under the support surface of the pallet. An air cushion is created between the bearing plate 4 of the rack cell 2 and the support surface of the pallet. Due to the action of inclined air jets, the pallet with the load is moved to the conveyor 1. The installation of pallets in the cells 2 of the rack is carried out in the reverse order. In this case, the inclined feed channels 6 are open, and the channels 5 are closed. With the help of an elevator-type lift (or any other lift), the pallet with the load can be transferred from the transport conveyor of the floor to the ground transport. The number of floors in the rack is not limited.

Let us consider a non-driven conveyor with the air cushion and inclined feed channels. In this case, the movement of the pallet with the load is possible only if the following conditions are met:

$$F_x \geq W_o + W_u = W_o + G \cdot \frac{a}{g}.$$

where F_x — the traction force created by the inclined jet of air; W_0 — the resistance to movement of the pallet with the load; W_u — the force of inertia during acceleration of the load to the required speed; G — weight of the pallet with the cargo; a — the acceleration of the pallet with the cargo, to achieve the required speed at the specified time; g — gravity acceleration.

The authors of previously published works [1, 2] and methods for calculating [4] the main parameters of air-cushion conveyors assumed that the resistance to movement was equal to the sliding resistance of the support surface of the pallet (load) on the bearing surface of the conveyor. Moreover, the height of the air cushion at all points was assumed to be the same, which is possible only if the gravity center of the load is located above the geometric center of the pallet.

However, the load may not be located in the center of the pallet, i.e. the center of gravity of the load does not coincide with the geometric center of the support surface of the pallet. In this case, the height of the air cushion under the pallet is different and depends on the eccentricity of the load location. Because of this, the points of application are shifted and the values of the drag and traction forces change, which depend on the height of the airbag. In addition, there are torque effects that tend to turn the pallet, which moves in the guide rails that limit its transverse displacement and rotation. At the points of contact of the pallet with the guides, friction forces arise that increase the total resistance (Fig. 2).

[1] Rabochiy G. M., Rumyantsev B. P. Opredelenie nesushchey sposobnosti ustroystv dlya beskontaktnogo peremeshcheniya gruzov [Determination of the load-bearing capacity of devices for contactless movement of goods]. Novoe v pod’emno-transportnoy tekhnike: tez. Vsesoyuz. nauch. konf., posvyashch. 60-letiyu kafedry "Pod’emno-transportnye mashiny i oborudovanie" MVTU im. N. E. Baumana [New in lifting and transport equipment: proc. of All-Union. scientific conf., dedicated to the 60th anniversary of the Department "Lifting and Transport Machines and Equipment" of the Bauman Moscow State Technical University]. Moscow. 1985. p. 36–37 (In Russ.).

[2] Bshesh N. Yu. Sovershenstvovanie konveyerov s vozdushnoy podushkoy, transportiruyushchikh shtuchnye gruzy: dis. … k-ta tekh. Nauk [Improvement of air-cushion conveyors transporting piece loads: authors thesis]. Lugansk, 1994. 179 p. (In Russ.).

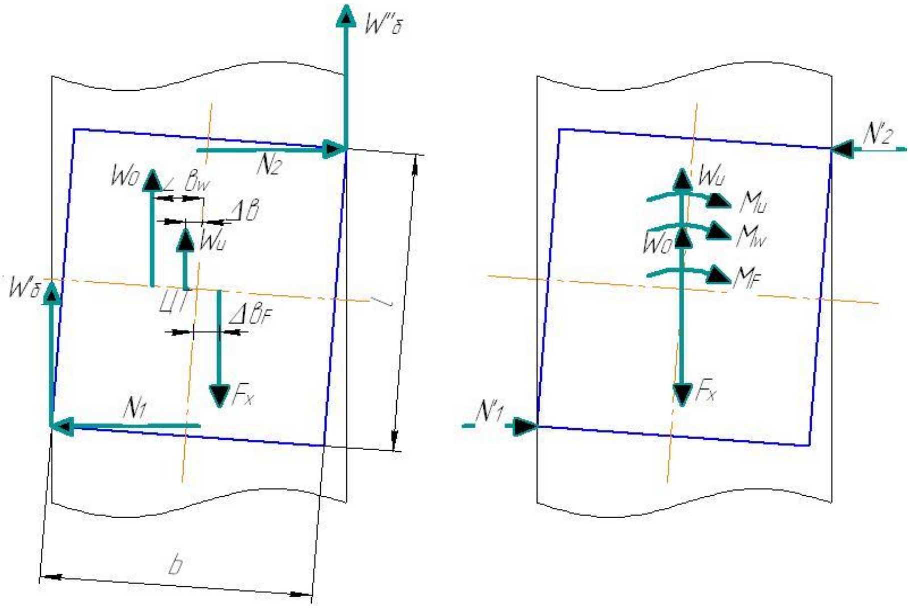

Fig. 2. Total resistance of the movement of the pallet with the load

Thus, the resistance to the movement of the pallet:

$$W_o = W_c + W_\delta ,$$

where W_c — the resistance from the pallet sliding on the bearing surface of the conveyor, W_δ — the resistance from friction against the guide rails.

The slip resistance can be determined by the formula:

$$W_c = G\left(f_1 \cdot e^{-6\frac{h}{\Delta}} + 0,0008 \right),$$

where G — the coefficient without the air cushion, h — the height of the air cushion, Δ — the height of the unevenness of the bearing surface of the conveyor.

Resistance from friction against the guide rails:

$$W_\delta = W_\delta' + W_\delta'' = (N_1 + N_2) \cdot f_2 = 2 \cdot f_2 \frac{M_F + M_w + M_u}{\ell} .$$

where M_F — the moment caused by the displacement of the traction force; M_W — the moment caused by the shift of the slip resistance; M_u — the moment caused by the displacement of the inertial forces during acceleration; ℓ — the length of the pallet.

$$M_F = F_x \cdot \Delta b_x ,$$

$$M_W = W_c \cdot \Delta b_w ,$$

$$M_u = \frac{G}{g} \cdot a \cdot \Delta b ,$$

where Δb_x, Δb_w, Δb — the values of the displacement of the points of application of the corresponding forces relative to the center of the pallet.

The traction force created by the jet of air coming out of the inclined feed channels can be described by the expression [6]:

$$F_x = P \cdot S \cdot C_x,$$

where P — overpressure in the conveyor receiver chamber, S — the bearing surface area of the pallet, C_x — traction force coefficient.

Using the results of previous studies [6], we have:

$$C_x = \frac{16\cdot\left(\frac{H+h}{\alpha}\right)^2\cdot\left[1-2\cdot\frac{H+h}{d}\cdot\left(1-e^{-0,5\frac{d}{H+h}}\right)\right]^2\cdot\frac{\overline{\Pi}^2}{\overline{S}_1}\cdot h^2\cdot\sin\alpha}{1+\frac{\overline{\Pi}^2}{2\cdot\overline{S}_1^2}\cdot h^2}.$$

where H — the depth of the chamber in the bearing surfaces of the pallet, d — the diameter of the feed channels.. $\overline{\Pi}$ — the ratio of the perimeter to the area of the bearing surface of the pallet:

$$\overline{\Pi} = \frac{\Pi}{S} = \frac{2\cdot(l+b)}{l\cdot b},$$

where ℓ — the length of the bearing surface of the pallet, b — the width of the bearing surface of the pallet.

$\overline{S}_1$ — relative area of feed channels:

$$\overline{S}_1 = \frac{\pi\cdot d^2\cdot n}{S},$$

where n — the number of feed channels in the area covered by the pallet.

The dependence of the traction force coefficient on the height of the air cushion within the studied limits is almost linear [6]. Therefore, we can suppose:

$$F_x = P\cdot S\cdot\frac{C_{x1}+C_{x2}}{2},$$

where C_{x1}, C_{x2} — the values of the traction force coefficient at the extreme points.

Then:

$$F_x = 8\cdot P\cdot S\cdot\frac{\overline{\Pi}^2}{\overline{S}_1}\cdot\mathrm{Sin}\,\varphi\cdot\left\{\begin{array}{l}\dfrac{\left(\frac{H+h_1}{d}\right)^2\left[1-2\cdot\frac{H+h_1}{d}\left(1-e^{-0,5\frac{d}{H+h_1}}\right)\right]^2 h_1^2}{1+\frac{\overline{\Pi}^2}{2\cdot\overline{S}_1^2}h_1^2}+\\ +\dfrac{\left(\frac{H+h_2}{d}\right)^2\left[1-2\cdot\frac{H+h_2}{d}\left(1-e^{-0,5\frac{d}{H+h_2}}\right)\right]^2 h_2^2}{1+\frac{\overline{\Pi}^2}{2\cdot\overline{S}_1^2}h_2^2}\end{array}\right\}.$$

where h_1, h_2 — the values of the height of the air cushion at the extreme points, φ — the angle between the vertical and the axis of the feed channel.

The lifting force that balances the weight of the pallet with the load can be determined [6]:

$$F_y = P\cdot S\cdot C_y.$$

where C_y — the lifting force coefficient:

$$C_y = \frac{1}{1+\frac{\overline{\Pi}^2}{2\cdot\overline{S}_1^2}h^2}.$$

If the gravity center of the load is shifted relative to the center of the pallet, the height of the airbag will decrease towards this shift. This will entail a change in the C_y. The nature of the dependence of C_y on h in the considered limits is close to linear [3], so:

$$C_y = \frac{C_{y1}+C_{y2}}{2},$$

where C_{y1}, C_{y2} — the values of the lifting coefficients at the extreme points.

Then:

$$F_y = F_{y1} + F_{y2} = \frac{1}{2} \cdot P \cdot S \cdot \left(\frac{1}{1 + \frac{\overline{\Pi}^2}{2 \cdot \overline{S}_1^2} h_1^2} + \frac{1}{1 + \frac{\overline{\Pi}^2}{2 \cdot \overline{S}_1^2} h_2^2} \right).$$

Considering the pallet with the load in equilibrium (Fig. 3), we determine the height of the air cushion at the extreme points.

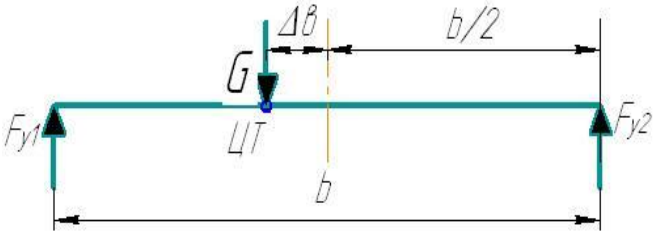

Fig. 3. Pallet with load in equilibrium

$$G\left(\frac{b}{2} + \Delta b\right) - F_{y1} \cdot b = 0, \quad F_{y1} = G\frac{b + 2 \cdot \Delta b}{2b},$$

$$G\left(\frac{b}{2} - \Delta b\right) - F_{y2} \cdot b = 0, \quad F_{y2} = G\frac{b - 2 \cdot \Delta b}{2b}.$$

Thus:

$$G\frac{b + 2 \cdot \Delta b}{2b} = \frac{P \cdot S}{2 + 4 \cdot \frac{(b + l)^2}{\overline{S}_1^2 \cdot b^2 \cdot l^2} h_1^2}.$$

From:

$$h_1 = \frac{\overline{S}_1 \cdot b \cdot l}{b + l} \sqrt{\frac{1}{2}\left(\frac{P \cdot b \cdot l}{G} \cdot \frac{b}{b + 2 \cdot \Delta b} - 1\right)}.$$

Similar to:

$$G\frac{b - 2 \cdot \Delta b}{2b} = \frac{P \cdot S}{2 + 4 \cdot \frac{(b + l)^2}{\overline{S}_1^2 \cdot b^2 \cdot l^2} h_2^2}.$$

From:

$$h_2 = \frac{\overline{S}_1 \cdot b \cdot l}{b + l} \cdot \sqrt{\frac{1}{2} \cdot \left(\frac{P \cdot b \cdot l}{G} \cdot \frac{b}{b - 2 \cdot \Delta b} - 1\right)}.$$

Denoting

$$\frac{G}{P \cdot S} = C_{y0},$$

we get:

$$h_1 = 0,707 \frac{\overline{S}_1 \cdot l}{1 + \frac{l}{b}} \sqrt{\frac{1}{C_{y0}\left(1 + 2 \cdot \frac{\Delta b}{b}\right)} - 1}.$$

$$h_2 = 0,707 \frac{\overline{S}_1 \cdot l}{1 + \frac{l}{b}} \sqrt{\frac{1}{C_{y0}\left(1 - 2 \cdot \frac{\Delta b}{b}\right)} - 1}.$$

The total resistance to the movement of the pallet with the load consists of:

— the resistance from sliding on the stationary surface of the conveyor;

— the resistance from friction against the guide rails, due to the displacement of the gravity center of the load relative to the center of the pallet.

The slip resistance depends on the height of the air cushion (h_1 to h_2 across the width of the pallet). The resultant is shifted relative to the center of the pallet by the value Δbw.

The height of the air cushion at the point of application of the resultant $h_ц$ can be determined from the equality of the areas bounded by the curve [6] (Fig. 4):

$$\omega = f_1 e^{-6\frac{h}{\Delta}} + 0,0008.$$

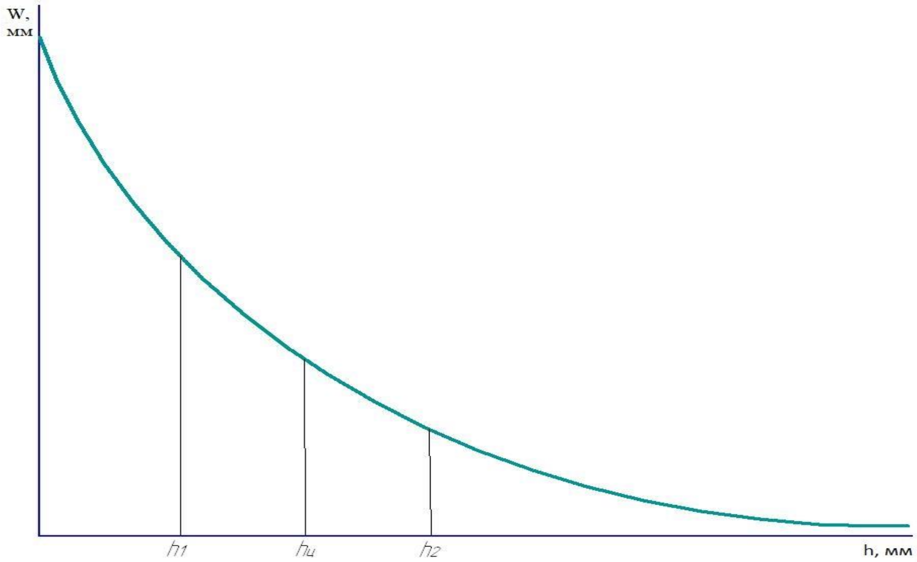

Fig. 4. Height of the airbag at the point of application

$$\int_{h_2}^{h_c}\left(f_1 \cdot e^{-\frac{6}{\Delta}h} + 0,0008\right)dh = \int_{h_c}^{h_1}\left(f_1 \cdot e^{-\frac{6}{\Delta}h} + 0,0008\right)dh.$$

After integration and simplification, we get:

$$\ell n h_c^2 = \ell n h_2 + \ell n h_1,$$

or

$$h_c = \sqrt{h_2 \cdot h_1}.$$

The value of the displacement of the point of application of the resultant sliding resistance forces (Fig. 5):

$$\Delta bw = b\left(\frac{1}{2} - \frac{\sqrt{h_1 \cdot h_2} - h_1}{h_2 - h_1}\right).$$

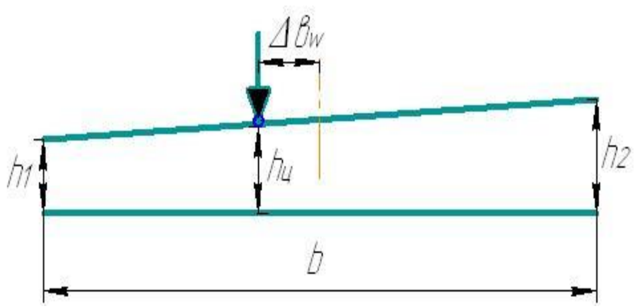

Fig. 5. The value of the displacement of the point of application

The resultant moment due to the displacement of the resultant is equal to:

$$M_w = W_c \cdot \Delta bw = Gb\left(f_1 \cdot e^{-\frac{6}{\Delta}\sqrt{h_1 \cdot h_2}} + 0,0008 \right) \cdot \left(\frac{1}{2} - \frac{\sqrt{h_1 \cdot h_2} - h_1}{h_2 - h_1} \right).$$

When the load is accelerated to the required speed, the inertia force is applied at the gravity center of the pallet with the load. The moment of this force relative to the center of the pallet with uniformly accelerated motion:

$$M_u = \frac{G}{g} \cdot a \cdot \Delta b .$$

This means that the resistance from the friction of the pallet on the guide rails with an off-center position of the load:

$$W_\delta = 2 \cdot \frac{f_2}{l} \cdot \left[\begin{array}{l} \frac{P \cdot S}{2} \cdot b \cdot \left(Cx_2 - Cx_1 \right) + G \cdot b \times \\ \times \left(f_1 \cdot e^{-\frac{6}{\Delta}\sqrt{h_1 \cdot h_2}} + 0,0008 \right) \cdot \left(\frac{1}{2} - \frac{\sqrt{h_1 \cdot h_2} - h_1}{h_2 - h_1} \right) + \frac{G}{g} \cdot a \cdot \Delta b \end{array} \right].$$

The condition for the movement of the pallet when the load is located off-center in the rack warehouse cell:

$$\frac{1}{Cy_0} \cdot \frac{Cx_1 + Cx_2}{2} = f_1 \cdot e^{-\frac{6}{\Delta}\sqrt{h_1 \cdot h_2}} + 0,0008 + 2\frac{f_2}{l} \times$$
$$\times \left[\frac{b}{2Cy_0} \left(Cx_2 - Cx_1 \right) + b\left(f_1 \cdot e^{-\frac{6}{\Delta}\sqrt{h_1 \cdot h_2}} + 0,0008 \right) \times \left(\frac{1}{2} - \frac{\sqrt{h_1 \cdot h_2} - h_1}{h_2 - h_1} \right) + \frac{a}{g} \cdot \Delta b \right] + \frac{a}{g}.$$

Acceleration of the movement of the pallet with the load in the warehouse cell:

$$a = \frac{g \cdot \frac{l}{b}}{\frac{l}{b} + 2 f_2 \cdot \frac{\Delta b}{b}} \times \left\{ \begin{array}{l} \frac{Cx_1 + Cx_2}{2Cy_0} - f_1 \cdot e^{-\frac{6}{\Delta}\sqrt{h_1 \cdot h_2}} - 0,0008 - 2 \cdot f_2 \cdot \frac{b}{l} \times \\ \times \left[\frac{Cx_2 - Cx_1}{2Cy_0} + \left(f_1 \cdot e^{-\frac{6}{\Delta}\sqrt{h_1 \cdot h_2}} + 0,0008 \right) \times \left(\frac{1}{2} - \frac{\sqrt{h_1 \cdot h_2} - h_1}{h_2 - h_1} \right) \right] \end{array} \right\}.$$

It can be seen that the acceleration of the movement of the pallet with the load depends on many factors. Some of them (the dimensions of the bearing surface of the pallet and the displacement value of the gravity center) are regulated by the characteristics of the transported cargo. The coefficients of friction and the height of the surface irregularities depend on the materials from which the conveyor is made. The optimal values of the diameter and angle of inclination of the feed channels were determined earlier [4, 7]. The necessary acceleration can be obtained by varying H, and P.

Conclusion. The analysis of methods and means of mechanization and automation of transport processes in rack warehouses has shown that the use of air-cushion conveyors reduces the time for performing individual operations, simplifies automation schemes, and makes it possible to create a safe automated or easily controlled transport and warehouse system. As a result, this approach will significantly reduce capital costs and operating costs.

The results of the conducted research were used to create a methodology for determining the main parameters of hovercraft transport devices with inclined feed channels. In the case of cargo transportation with a displaced gravity center, this approach allows you to significantly expand the scope of these devices and ensure their reliable and safe operation in the storage areas of rack warehouses.

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Contribution of the authors:

V. A. Turushin — formulation of the main concept, goals and objectives of the study; A. M. Redko — scientific supervision, analysis of the research results, revision of the text, correction of the conclusions; N. V. Turushina — development of the software package, menu design, calculations.