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On Improving The Safety Of Operators Of Vehicles Used In Agriculture

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Abstract. The agro-industrial complex of the Russian Federation regularly is in the top three most traumatic industries. The analysis of industrial injuries shows that in the conditions of agricultural production, there is a tendency to an increase in the share of injuries associated with a number of design flaws in agricultural machinery, maintenance and repair facilities, including dump trucks, and in recent years there has been a steady increase in the share of dump rolling stock in agriculture.

The problem of injury hazard of transport dumping equipment used in agricultural production is the spontaneous (emergency) lowering (falling) of the loading platforms of the dump trucks, dump trailers, in particular, due to the failures and malfunctions of hydraulic lifting mechanisms. At present, more than 70% of the received serious and fatal injuries in one way or another are associated with machinery, herewith first of all operators (drivers, tractor drivers, machine operators) of transport and mobile energy facilities are injured.

The authors see a solution to the operator safety problem by technical methods, that is, to increase the safety of operators of transport and mobile energy vehicles is possible by improving a hydraulic drive with the help of the redundant safety and interlocking systems, the operation of which does not depend on the operability of the hydraulic drive and does not require outside operator intervention.

The article proposes technical safety devices for a body of a dump truck, a loading platform of a dump trailer equipped with a hydraulic tipping device. The devices will allow blocking the dump truck body, the loading platform in a raised position when the hydraulic drive is depressurized, that gives an opportunity to the operator to avoid injury when he is working in the dangerous zone under the body or loading platform of the trailer.

The use of interlocking and safety technical devices developed by the authors allows reducing the injury rates in agricultural production, to increase the reliability and safety of transport and mobile energy equipment used in agriculture.

The experiment researches have shown that the probability of operators' protection by the developed technical devices is 0.98.

Keywords: safety, dump truck, hydraulic drive, hydraulic cylinder, dump trailer, loading platform, safety stop.

Introduction. Today, the Russian agro-industrial complex (AIC) is actively involved in the program to replace imported agricultural products. Despite the crisis, the demand for domestic products in the country is constantly growing; in 2020, an increase in the volume of agricultural cargo transportation is forecasted to reach 7.2 billion tons. However, the implementation of such plans in the mechanized transport and technological process of agricultural production is possible only with the use of modern, high-performance and safe transport equipment, with a hydraulic drive. The hydraulic drive, already now, provides the mechanization of all main and auxiliary operations in the agricultural transport and technological process.

Vehicles are an integral part of transport and technological processes in agricultural production, with a stable growth in the share of dump rolling stock observed annually. However, as statistics show, the growth in the volume of agricultural transport by dump equipment is accompanied by an increase in industrial injuries.

In our country and abroad, to ensure the lifting and lowering of cargo dump platforms in 95% of vehicles in agricultural production, tipping devices with a hydraulic drive are used.

The use of a hydraulic drive has a number of advantages over other drives of vehicles used in agriculture: small dimensions and weight, the ability to smoothly control the speed of lifting (lowering) the platform, working bodies of mobile machines; reduction in weight and load on working equipment in general; reducing the severity and safety of operators. However, as practice shows, the increase in the number of hydraulic equipment also has a negative side – the danger of an increase in the number of accidents associated with a number of design flaws in the hydraulic drive of agricultural transport equipment. Failures of hydraulic drive elements account for more than half of the total number of failures of technical systems of agricultural machines. The problem of safe operation of agricultural transport equipment with a hydraulic drive consists in unauthorized (emergency) spontaneous lowering (falling) of the platform, due to a violation of the tightness of the moving joints. Most often, the hydraulic drive fails due to rupture of high pressure hoses and seal defects [5, 6, 7, 12].

The main and most loaded element of such a drive is a single-acting hydraulic cylinder, which provides quick lifting of dump loading platforms, regardless of external load.

To slow down the working process of lowering the load by a cargo dump platform, throttle devices and retarding valves have been developed and used in our country and abroad (Figure 1).

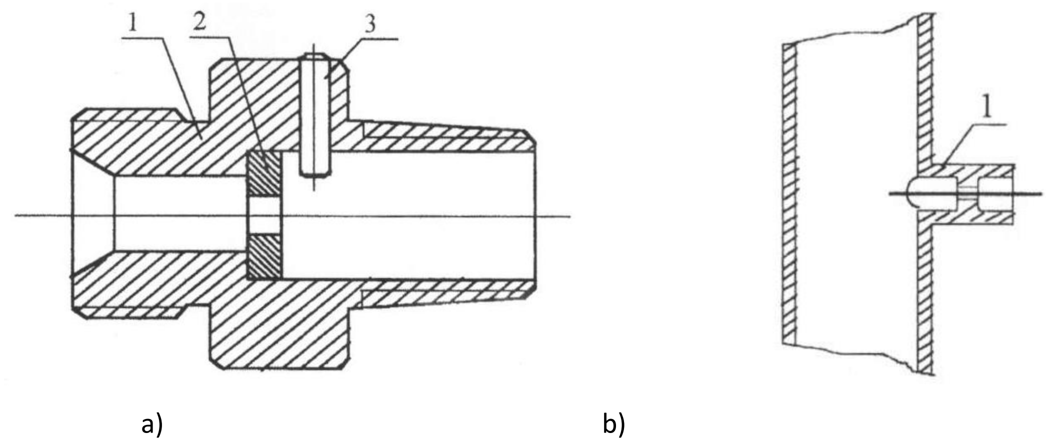


Figure 1 - Means of regulating the speed of lifting (lowering)
of hydraulic parts and mechanisms:
a) retarding valve: 1 - body; 2 - washer with a calibrated hole; 3 - pins; b) throttle device: 1 - fitting with a calibrated hole

The retarding valve is screwed into the hole of the hydraulic cylinder, a hose from the hydraulic system of the tractor or car is connected to the other valve fitting. This valve allows a quick lifting of an agricultural mounted machine and a slower lowering of it [21,22,23,26,].

In order to increase the time of lowering the platform (working body), it is necessary to accordingly reduce the area of the calibrated hole in the washer. However, a decrease in the cross-section of the hole leads to negative consequences: the lifting time of the platform increases (which is not economically profitable), most of the machine's power is spent on heating the oil when it is bypassed through the calibration hole, which is highly undesirable.

Materials and methods. During the functioning of man-machine systems, in the conditions of agricultural production, in some cases, for various reasons, an environment arises in which the operator can be exposed to hazardous production factors leading to a serious or fatal outcome. In particular, for dump trucks, the raised cargo platform of the body serves as a hazardous production factor, while the space under the raised platform is called the dangerous zone [11].

As an example, let us consider the danger zone created by the cargo platform of a car - dump truck GAZ - SAZ –3597 - 01 (Figure 2).

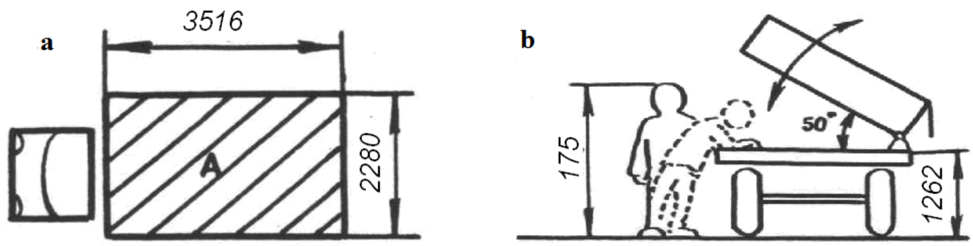


Figure 2 - Scheme for determining the danger zone of the cargo platform of a car – dump truck: a) top view, b) rear view

Obviously, zone A in Figure 2a is dangerous, since injury to the person under it in the event of an emergency lowering (falling) of the cargo platform is 100% likely. This statement is due to the fact that the speed of the emergency lowering (falling) of the cargo platform is less than 1.5 seconds, while the person, during this period of time, physically does not have time to leave the danger zone, since the response time of the person is more than 2 seconds. Depending on the position of the body at the moment the platform falls (standing, bent position), the operator may get injured in the head, shoulders or back, in some cases the injuries are fatal.

However, the danger zone is not limited to the outline of the loading platform. Consider the case (Figure 2b), when a person's steps are outside the loading platform, but there is a possibility that the human body is not in an upright position, but bent in the lower back, then the head and upper body of the person falls into zone A. Thus, it is dangerous the zone expands, an additional hazardous zone B is formed (Figure 3).

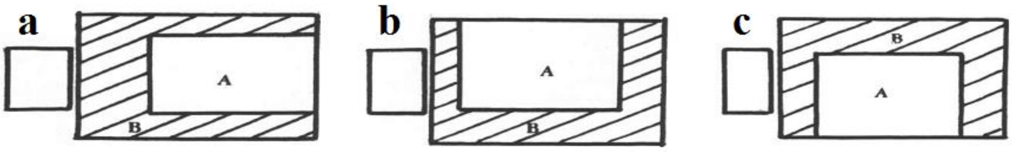


Figure 3 - Scheme of additional danger area B of the cargo platform
of the vehicle – tipping dump truck:
a) back, b) right, c) left.

It has been experimentally established that, depending on the height of a person, the width of the additional danger zone B ranges from 0.70 to 0.90 m.

The operator is forced to stay in the danger zone, since maintenance and repair work on the hydraulic tipping device can only be carried out when the operator is in the mentioned zones [10, 11].

Cases were also noted when, in the event of an accidental breakage of the hose, upon elimination of failures in the hydraulic system of a tipping device with a hydraulic drive, a sharp lowering (falling) of the platform occurs. People in the area under the raised platform do not have time to leave the danger area and are injured (in most cases, fatal). To ensure the safety of the operator working under the raised platform, dump trailers and dump trucks with lifting platforms are equipped with safety stops (Figure 4) [1,3,10].

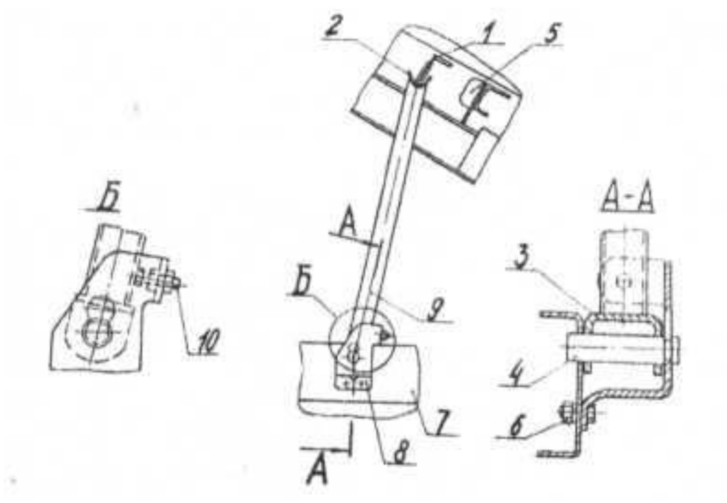


Figure 4 - Stop of the car platform - dump truck:

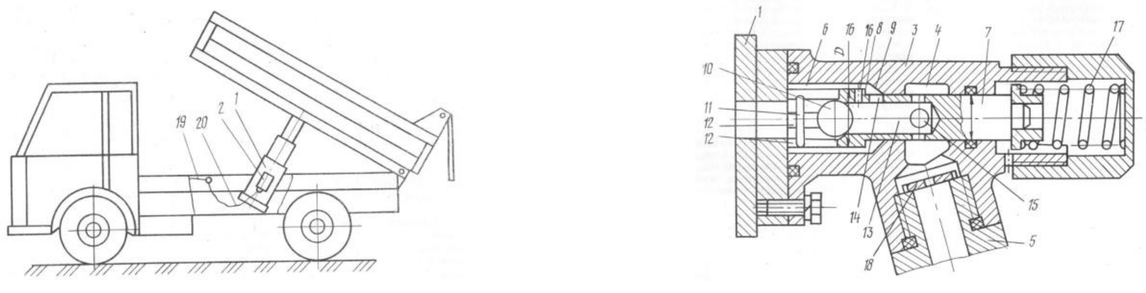
1 - top support; 2 - bracket; 3 - plug; 4 - axis; 5 - additional support; 6 - bolted connection; subframe spar; 8 - bracket; 9 - rack; 10 - adjusting bolt

It takes about 70 seconds to install the safety stop. The safety stop is installed when the platform is fully raised, when two holes coincide, where the safety stop is installed, which is not always done by both the driver and other workers. The study of dump transport has shown that currently there are no car lifting devices for rigid fixation of the cargo platform [1,10].

However, as practice and injury analysis show, maintenance personnel rarely use a safety stand when working under a raised platform.

To solve the problem of ensuring the safety of operators, scientists have developed a large number of technical devices that exclude injury to operators who are in the lifting – lowering zone of the cargo dump platform.

To prevent spontaneous (unauthorized) lowering (falling) of cargo dump platforms of dump trucks, a hydraulic safety device has been developed. The device is a speed limiter for lowering (falling) of the car body – dump truck shown in Figure 5.



a) b)

Figure 5 - Car with hydraulic dump platform tipper

Figure 6 shows a device for automatic control of the speed of lowering (falling) of a dump platform of a car – a dump truck, developed by G.P. Chernyak, V.K. Dobrinets, I.A., Kitaychik I.A.

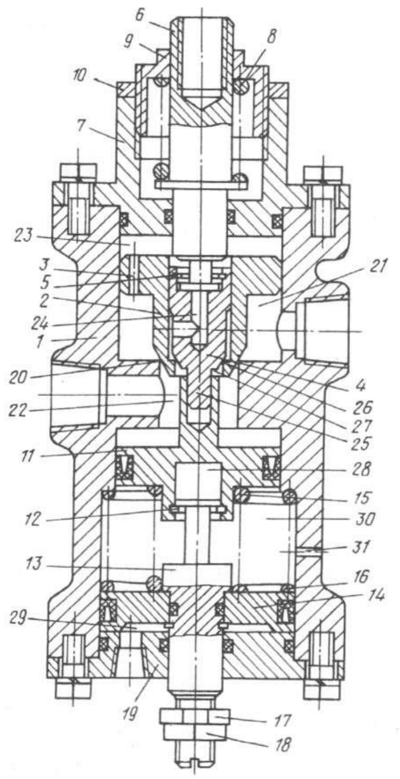


Figure 6 - Longitudinal section of a device for automatic control of the lowering speed of the dump truck platform

This device allows automatically, without operator intervention, to adjust the platform lowering speed, i.e. the possibility of the operator being under the platform, in the danger zone, is excluded, however, the device is complicated to manufacture and requires the operator to be in the danger zone when unlocking the dump platform. Also, the disadvantage of the device is the impossibility of fixing the platform in the raised position, in case of mechanical failures of the hydraulic drive

Devices developed by: Afanasyev A.I., Vysotsky M.S., Kryzhanovsky N.K., Ksenevich I.P., Makeev A.Yu, Fleur D.E., Filatov V.I.

Figure 7 shows an adjusting and locking device that prevents spontaneous lowering (falling) not only of cargo dump platforms of transport machines, but also of hydraulic working bodies of lifting machines, which was developed by I.T. Agapov [1].

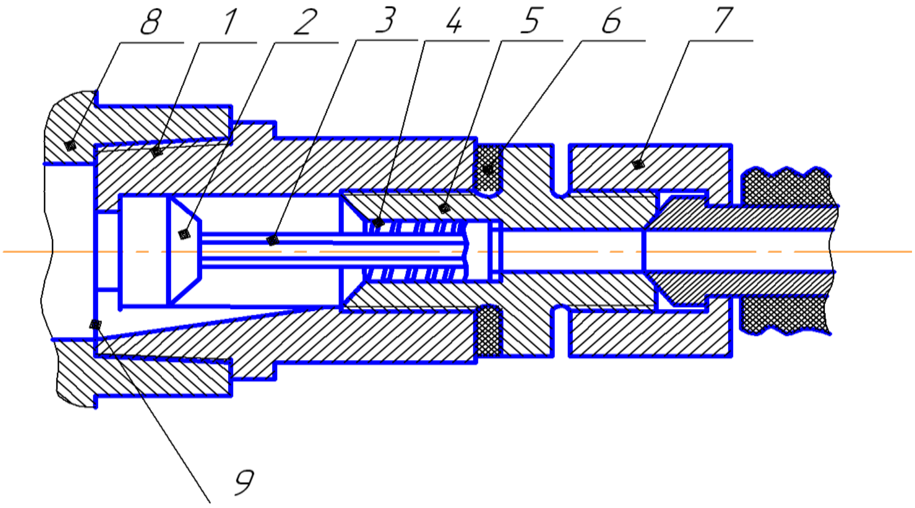


Figure 7 - Adjustment - locking device

In order to save the life and ensure the safety of the operator of the construction transport machine, in the event of an unauthorized (emergency) lowering (falling) of the platform, working bodies, it is necessary to ensure the maximum time of lowering (falling) of the platform.

The advantage of the device is:

- ease of manufacture of the device, available for any agricultural enterprise;
- automatic blocking of the dump platform in case of leakage of the hydraulic drive.

The disadvantage of this device is the need for the operator to be in the danger zone (under the platform) when unlocking the platform after the device is triggered.

A promising direction, according to many scientists, is the development of technical safety devices located in the hydraulic cylinder itself. In particular, V.V. Ostashenkov and D.N. Machurin proposed to install a three-stage telescopic hydraulic cylinder as a hydraulic cylinder for dump trucks, the diagram of which is shown in Figure 8.

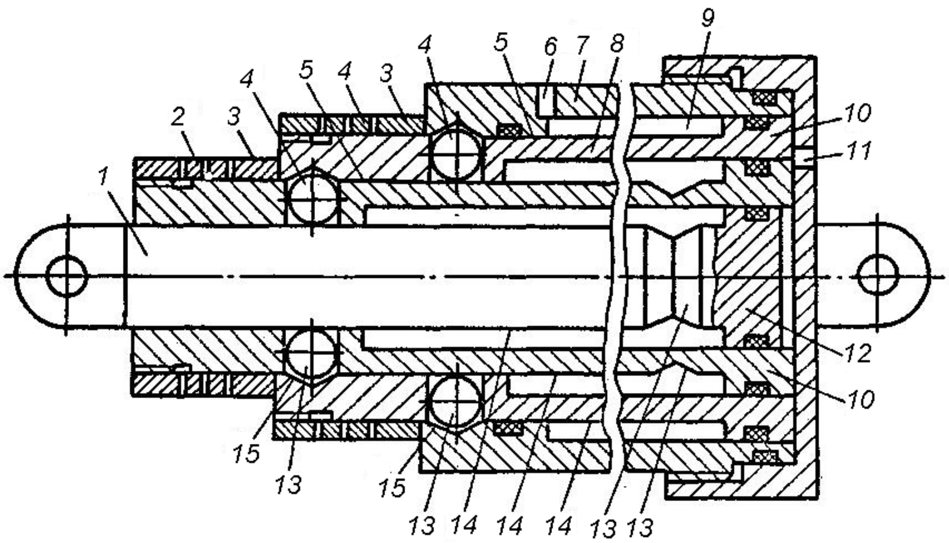


Figure 8 - Scheme of a multistage telescopic hydraulic cylinder:

The advantage of this device is the presence of means for fixing the platform in the hydraulic cylinder, the disadvantage is the presence of the operator in the danger zone when unlocking the ball locks.

The performed search and analysis of literary and patent sources containing a description of modern technical systems that prevent unauthorized (emergency) lowering (falling) of platforms allows us to classify these systems according to the following main features (Figure 9) [10].

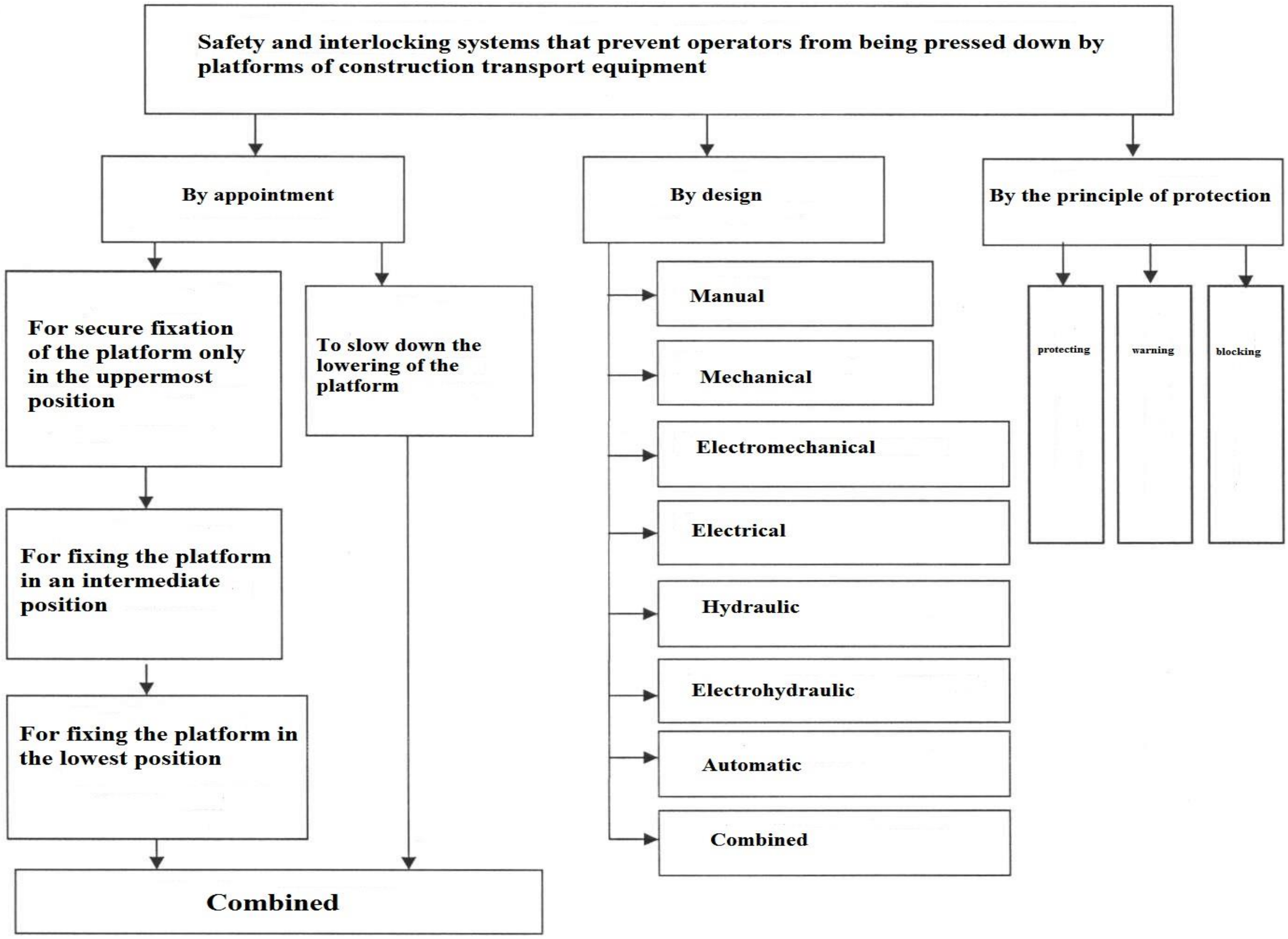


Figure 9 - Classification of safety and interlocking systems

Means to prevent spontaneous (unauthorized lowering (falling) of cargo dump platforms) also include technical safety equipment developed by: V.S.Shkrabak A.R.Arutyunyan, A.I.Baranovsky, Wilhelm Wetzel, Yu.A. Vishnyakov, A.D. Glushenko, D.I. Kanashka, A.M. Nesterenko, A.S. Melik - Sarkisyants, V.S. Smirnov, N.N. Tulchinsky, A.V. Shamanin, N.V. Firsov and others.

The purpose of the work is to develop methods and means to improve the safety of transport and mobile energy equipment used in agricultural production, including when the hydraulic system of the hydraulic drive is depressurized, in order to ensure the safety of the operator.

The authors propose to achieve the goal set in the work using technical methods:

1. Ensuring operator safety by distance. At the moment of emergency lowering (falling) of the dump platform, the operator must be outside the danger zone, for example, in the cab.

2. Ensuring the safety of the operator with time. Technical safety devices must provide such a time of lowering (falling) of the tipper platform, which is sufficient for the operator to leave the danger zone.

Results and discussion. Studies by the scientists of the All-Russian Scientific Research Institute of labor protection of the Ministry of Agriculture of the Russian Federation I.V. Galianov, A.I. Gavrichenko, Yu.D. Olyanich, A.I. Pantyukhin show that in agricultural production the share of injuries associated with machinery in the agro-industrial complex is more than 70%.

During the maintenance and repair of hydraulic drives of platforms and working bodies of agricultural mobile machines, from 5 to 30 people die annually, in a traumatic situation – crushing by lowering platforms, other hydraulic parts and mechanisms, violation of safety requirements by operators, in the form of dangerous actions of victims, have become the main group of reasons deaths in the agro-industrial complex of the Russian Federation (39.2%).

The main causes of accidents with fatalities of workers injured in the agro-industrial complex were:

- performance of technical operations under the platform of agricultural transport equipment in the raised position – 30.7%;

- use of defective or non-use of protective devices – 3.2%,

- operating with machine units with the engine running 10% and others.

A rather high share of industrial injuries (27.2%) is associated with technical malfunctions and structural and production shortcomings of self-unloading transport equipment [2,4,8,17,20].

Figure 10 presents a list of malfunctions that led to the death of the operator.

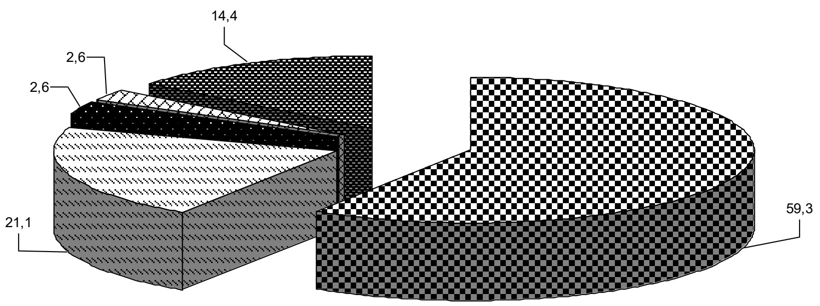


Figure 10 - List of malfunctions that led to the death of the injured: malfunction of the hydraulic drive – 59.3%; exit from the socket of the ball joint – 21.1%; breakage of the rear support of the bracket – 14.4%; body failure – 2.6%; other faults – 2.6%

From the information given in Figure 10, it can be seen that the largest number of fatal injuries occurs due to a malfunction of the hydraulic drive (59.3%) and exit from the ball joint socket (21.1%).

Investigation of the causes of accidents revealed that the most dangerous sources of injury were cars - dump trucks (58.0% of cases), dump trailers – 23.2%, trucks – 10.1% and other vehicles.

Distribution of failures by systems and devices of agricultural transport equipment is shown in Figures 11 and 12.

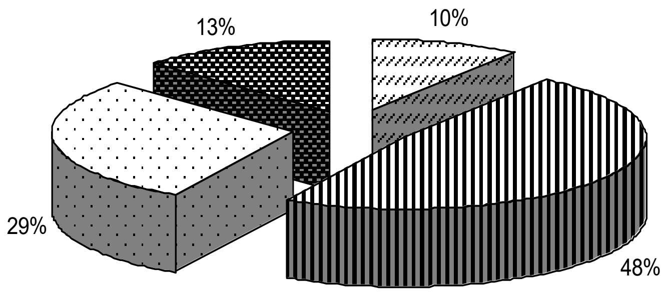


Figure 11 - Distribution of failures in the systems of hydraulic machines: hydraulic drive – 48%; electric drive – 29%; elements of mechanical transmissions – 13%, engine – 10% and others

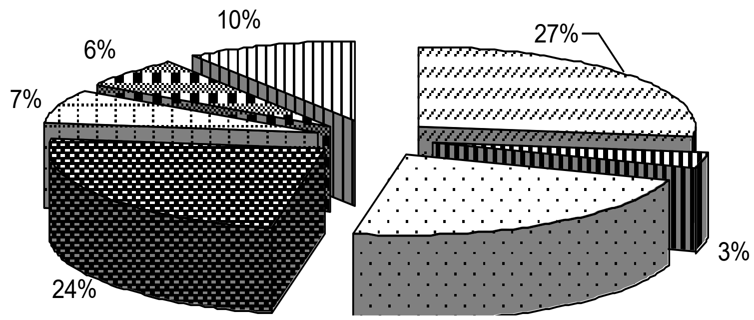


Figure 12 - Distribution of faults and failures in the hydraulic drive of hydraulic machines: hydraulic hoses – 27%; seals – 24%; hydraulic cylinder seals – 23%; control equipment – 10%; pumps – 7%; quick-detachable connections – 6%; other reasons – 3%

Every year, up to 90% of injuries associated with the operation of platforms of dump trucks are fatal and serious [2, 5, 22].

To solve the problem of operator safety, we offer a single-acting hydraulic cylinder as the hydraulic power cylinder of the cargo platform of a dump truck, in which the rod is released due to the hydraulic drive of the dump truck, and lowering due to the platform's own weight (Figure 13) [9, 13].

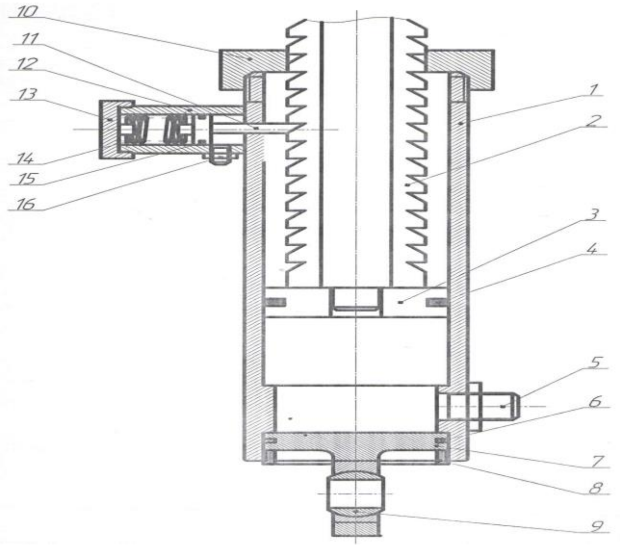


Figure 13 - Hydraulic cylinder

The hydraulic cylinder consists of a body 1, a rod 2 with special slots for retainers, a piston 3 with seals 4, a fitting 5, an ear-type cylinder attachment unit 7, a shaped washer 8, a spherical joint 9, a cover 10.

To the body of the hydraulic cylinder, bolts (not shown in Figure 13) fasten two cylinders with clamps (one is not shown in the figure). The cylinders consist of a body 12, a retainer 11, a cover 13, a spring 14, and a fitting 16. The piston of the lock has seals 15. The fittings of the two cylinders are connected by a pipeline (not shown in Figure 13).

Power hydraulic cylinder works as follows. To extend the rod and lift the loading platform, the working fluid, under pressure, through the fitting 5 is fed into the sub-piston cavity under the rod. In the cavity, pressure begins to increase, while the cylinder rod begins to move out of the housing 1, and the load platform begins to rise. When the rod 2 moves, the clamps 7 do not prevent the extension of the rod 2, but under the action of the springs 10, they always take place in the slots of the rod 2.

To remove the rod and lower the platform, pressure through the fitting 11 is supplied to the sub-piston cavity of the retainer 7. Overcoming the resistance of the spring 10, the retainer 7 begins to move to the left, the retainers 7 come out of the slots of the stem 2, the stem 2 is released, and the platform begins to lower under its own weight.

In the event of an emergency lowering (falling) of the cargo platform (when the hydraulic drive is depressurized, for example, due to the destruction of the hydraulic hose), the clamps will take place in the slots on the rod 3, the platform will stop, while the life of the operator, who could be in the danger zone (under the cargo platform) will be out of danger.

In the upper and lower parts of the hydraulic cylinder there are lug assemblies on which it rests and is attached to the frame and cargo platform of the trailer (car body – dump truck) by means of bolted connections.

To solve the problem of safety of operators of self-unloading dump equipment, a locking-regulating deviceю The locking-regulating device consists of a body 1, which houses a valve 2, a cover with a fitting 3, a sleeve 4, a spring 5, a cover 6; nut with washer 7, fitting 8, throttle channel 9 (Figure 14) [1, 21, 22, 24, 27].

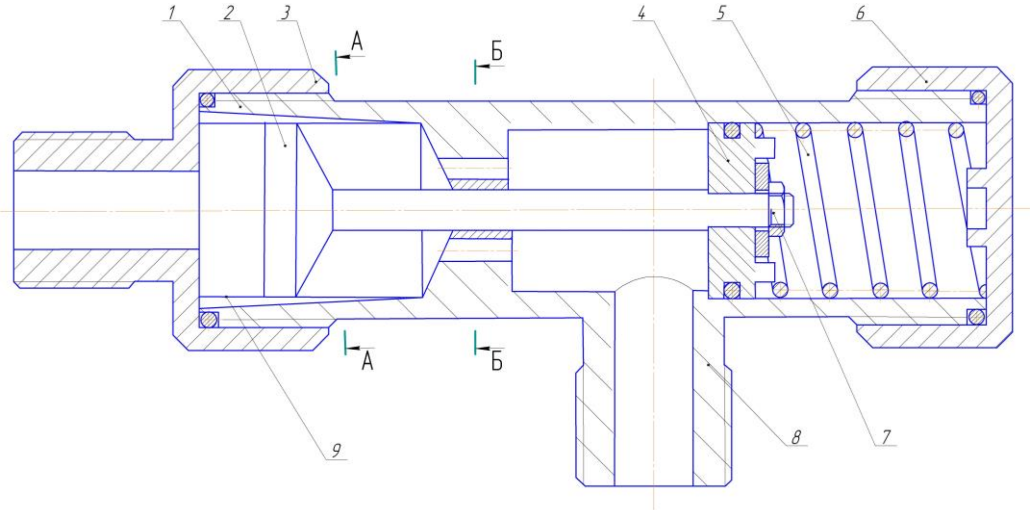


Figure 14 - Scheme of the locking-regulating device

The locking-regulating device works as follows. During lifting of the platform with a load using a hydraulic cylinder, the valve 2 under the influence of the spring 5 is in the extreme left position, due to which the working fluid flows out through the maximum section of the throttle channels 9. This ensures the required lifting speed of the load. When the platform is lowered without load, increased pressure is created at the outlet from the fitting 8. Under the influence of the increased pressure, the piston 2, overcoming the resistance of the spring 5, moves to the right. Since there are throttling channels 9 on the walls of the housing 1, the area of the throttling holes decreases when the valve moves. The change of the channels is chosen in such a way along the length, which ensures the constancy of the platform lowering speed at different loads, within the limits of the calculated carrying capacity.

When the hose breaks, the pressure at the outlet from the fitting 8 drops to zero, valve 2, compressing the spring, shifts to the right, while valve 2 sits in the valve seat of body 1, blocking the passage of the working fluid, fixing the platform in a raised position.

The connection diagram of the locking-regulating device to the hydraulic cylinder of the platform hydraulic drive is shown in Figure 15.

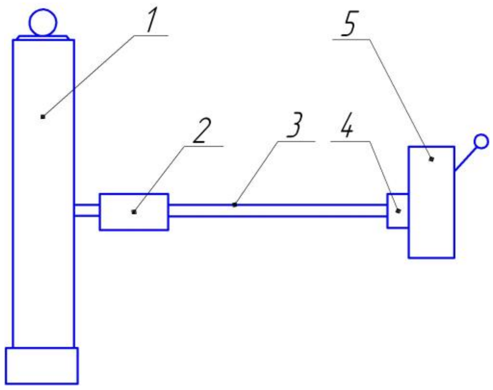


Figure 15 - Connection scheme of the locking-regulating device in the hydraulic drive of the platform: 1 – cylinder; 2 – locking-regulating device; 3 – hydraulic hose; 4 – automatic regulator;

5 – distributor

The operational characteristics of the platform locking and regulating device developed by the author were investigated on a 2PTS-6 dump trailer. As basic (comparative) samples, the retarding valve and the choke with a calibrated hole, which are currently used on dump platforms, were simultaneously investigated.

The research results are shown in Table 1.

Table 1 - Platform lowering and lifting times

Lowering, t, s						Lifting, t, s					
Platform weight without load = 1164 kg			Platform weight with load = 2664 kg			Platform weight without load = 1164 kg			Platform weight with load = 2664 kg		
1	2	3	1	2	3	1	2	3	1	2	3
54.1	39.1	26.1	54.1	29.1	21.1	19.1	19.1	19.1	59.1	61.1	59.1
54.1	41.1	29.1	54.1	31.1	21.1	19.1	19.1	19.1	61.1	61.1	59.1
54.1	40.1	27.1	54.1	30.1	21.1	19.1	19.1	19.1	60.1	61.1	59.1
54.1	40.1	27.1	54.1	30.1	21.1	19.1	19.1	19.1	60.1	61.1	59.1

The results of comparative studies have shown that the installation of a locking-regulating device on the working hydraulic cylinder of the platform allows providing, in contrast to the compared devices, a retarding valve and a choke with a calibrated hole, a constant time for lowering the platform. Together with the installation of the device, it does not affect the set technological, indicated in the manual, the lifting time ($t_{device} = t_{retard\ valve} = t_{colibrated\ hole}$).

As can be seen from the data in Table 1, the installation of the developed device made it possible to provide, in contrast to the compared devices, a constant time for lowering the platform. The discrepancy between the estimated t_e = 56.36s and the actual t_a = 54.1s with the platform lowering time did not exceed 4.19%.

The developed device for regulating the lifting and lowering speed of the cargo dump platform ensures the safety of the hydraulic drive.

The device for regulating the speed of lifting-lowering the cargo dump platform is shown in Figure 16.

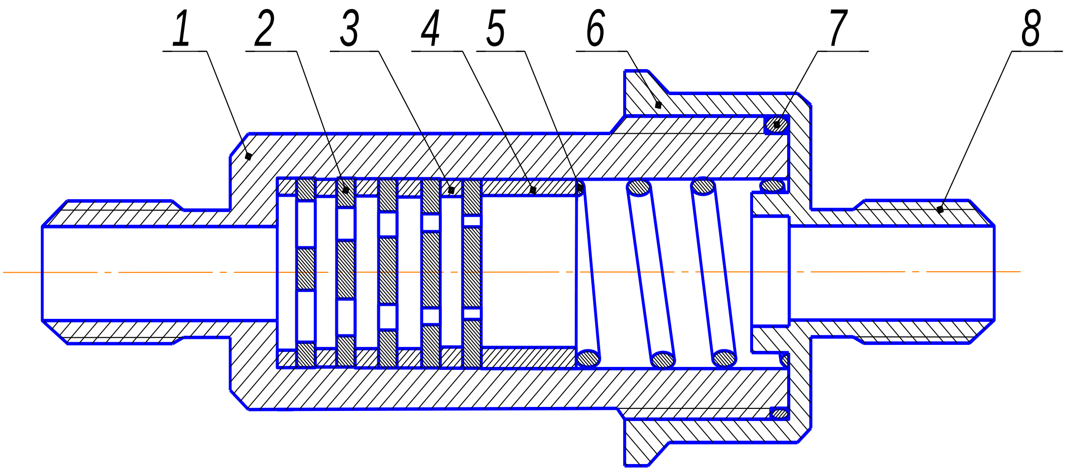


Figure 16 - Device for regulating the speed of lifting - lowering the cargo dump platform:

1 – case; 2 – throttle washers; 3 – rings; 4 – bushing 4; 5 – spring; 6 – cover; 7 – seals; 8 – union

Body 1, through an angle adapter, is attached to the union of the hydraulic cylinder. The nut of the high pressure hose from the oil pump of agricultural transport equipment is screwed onto the fitting 8; the sleeve is not shown in Figure 16. The rings, bushing and orifice washers are kept from turning in the body by a slot in the body. For the tightness of the joints, fluoroplastic and rubber rings 7 are used.

The lifting-lowering speed control device works as follows. During lifting of the platform with the help of a hydraulic cylinder, the working fluid under pressure is supplied to the hydraulic cylinder through the fitting 8 of the device for regulating the speed of lifting-lowering the cargo dump platform. The speed of lifting (lowering) speed regulation is carried out by the selection of throttle washers [15].

In Figure 16, the arrow indicates the place of installation of the device for regulating the speed of lifting - lowering the cargo dump platform into the hydraulic drive of the platform, in experimental studies.

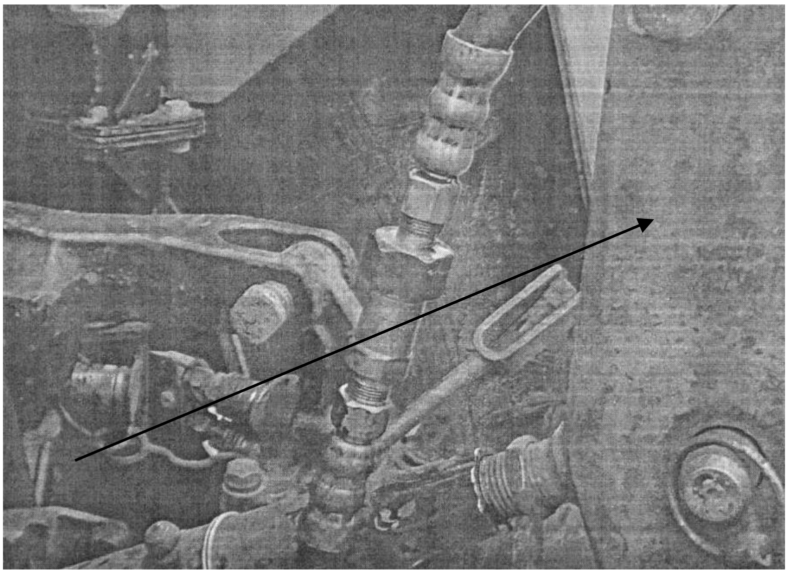


Figure 16 - Installation of a device for regulating the speed of lifting-lowering the cargo dump platform in a hydraulic drive

As noted earlier, the second most important reason for the fall of the dump loading platform is the exit from the socket of the ball joint – 21.1%

Investigation of the hydraulic cylinder attachment system, both to the frame and the vehicle platform, showed that during operation there are malfunctions of these units associated with the disconnection of fasteners, in particular the hydraulic cylinder head and, first of all, with the platform [14, 15, 16, 19, 28, 29, 30].

To identify the causes of this problem, we will carry out studies of the tolerance field of the fastener for the largest and smallest values.

The diagram of fastening the cylinder head in the support heel of the platform is shown in Figure 17.

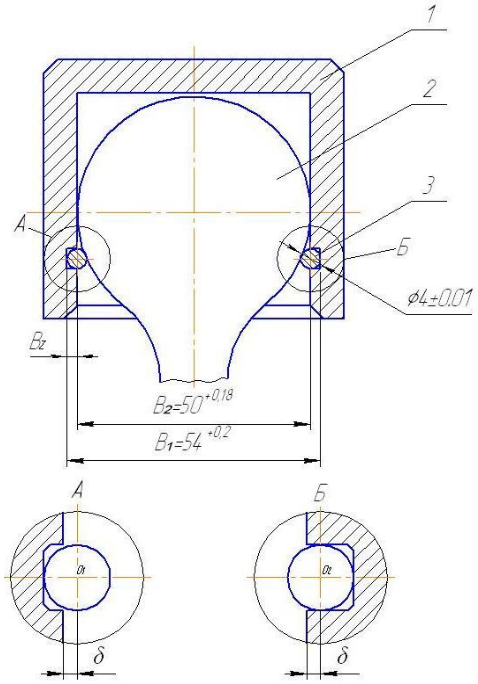


Figure 17 - Diagram of the hydraulic cylinder attachment to the platform or car frame:

A – The scheme of the position of the center of the retaining ring at B_{Kmin}; B – the diagram of the position of the center of the retaining ring at B_{Kmax}: 1 - heel, 2 - ball head of the hydraulic cylinder; 3 - retaining ring.

The measured value of the depth of the groove for the retaining ring, B_K is equal to:

$$B_K = \frac{B_1 - B_2}{2} = \frac{54.201 - 50.18}{2} = 2.01mm$$

The value of the tolerance of the size of Gr when calculating for the largest and smallest is equal to:

$$\delta B_Z = \sum_{i=1}^{n} \delta B_i = 0.18 + 0.201 = 0.381mm$$

The deviations for the lower and upper limits will be equal

$$B_K^B = \frac{0.381}{2} = 0.191mm$$

$$B_K^H = -\frac{0.38}{2} = -0.191mm$$

Then,

B_{KMAX} = 2 + 0,191 = 2.191 mm,

B_{KMIN} = 2 – 0,191 = 1.819 mm

With an average scattering coefficient of dimensions equal to K_{CP} = 1.51, the tolerance for the B_K gap will be equal to:

$$B_K = K_{CP}\sqrt{\sum_{i=1}\delta B_i^2} = 1{,}51\sqrt{0{,}201^2 + 0{,}18^2} = 0.41mm$$

$$B_K^B = \frac{0.41}{2} = 0.205mm$$

$$B_Z^H = -\frac{0.41}{2} = -0.205mm$$

The results obtained showed that:

B_{Zmax} = 2.21 mm.

B_{Zmin} = 1.81 mm,

In this case, the diameter of the snap ring is:

d_{max} = 4.015 mm

d_{min} = 3.995 mm

Studies show that when measuring the study of the tolerance field for the largest and smallest value of the size of the recess for the retaining ring, the situations were investigated when the size of the recess had a minimum value and the diameter of the retaining ring was the largest. With such values of the dimensions of the hydraulic cylinder attachment unit, the center of the diameter of the retaining ring is located outside the center of the groove, which necessarily leads to the emergence of additional dynamic forces pushing the retaining ring out of the groove.

It is possible to calculate the forces acting on the retaining ring in the cylinder attachment point.

A diagram of the forces acting on the retaining ring is shown in Figure 18.

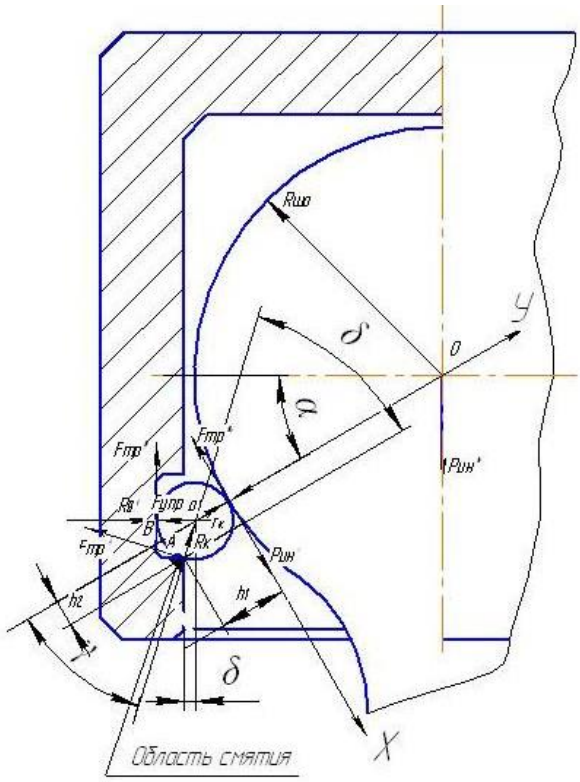


Figure 18 - Scheme of the forces acting on the retaining ring in the hydraulic cylinder attachment point

To perform the calculation, it is possible to determine the values of the reactions R_A and R_B, for this the authors compose an equation for the projections of forces on the X-axis and Y-axis:

$$\sum F_Y = 0;\ -F^{m}_{ИН} - P_{УПР}\cos\alpha + R_B\cos\alpha - F^{B}{}_{TP}\sin\alpha + R_A\cos\alpha - F^{A}{}_{TP}\sin\gamma = 0$$

$$\sum F_X = 0;\ F^{\tau}_{ИН} - F^{O_1}_{TP} + R_B\sin\alpha + F^{B}{}_{TP}\cos\alpha - R_A\sin\gamma - F^{A}{}_{TP}\cos\gamma - P_{УПР}\sin\alpha = 0 \quad (1)$$

Assuming that:

$$F^{A}_{TP} = R_A tg\varphi;\ tg\varphi = 0{,}15;\ F^{A}_{TP} = 0{,}151R_A;\ F^{O_1}_{TP} = 0{,}151R_{B_y};$$

$$P_{УПР} = 0{,}171F^{B}_{ИН}.$$

Solving the system of equations (2.16), we get:

$$R_A = 0{,}9398F^{B}_{ИН}, \quad R_B = 0{,}0776F^{B}_{ИН}.$$

The equation of moments of forces relative to point A has the form:

$$M_A = -F_{ИН}^B \cos\alpha h_1 + F_{ИН}^B \sin\alpha \times 0{,}15 h_1 + F_{ИН}^B \sin\alpha \times h_2 + \\ + 0{,}0174 F_{ИН}^B \times 2k - 0{,}07752 F_{ИН}^B \times 2k = 0 \quad (2)$$

Forces with a plus sign hold the retaining ring in the groove, with a minus sign they push it out.

Let us carry out transformations, for this we divide the terms of equation (2) by $F^B_{ИН}$ and substituting the values of the arms (3):

$$h_1 = r_K + r_K \cos\gamma = r_K (1 + \cos\gamma)$$
$$h_2 = r_K \sin\gamma \quad (3)$$

We get:

$$\sin\alpha \times 0{,}15 r_K (1 + \cos\gamma) + \sin \times r_K \sin\gamma = \cos\alpha r_K (1 + \cos\gamma) + 0{,}06051 r_K \quad (4)$$

where r_K is the radius of the ring.

Replace cosγ by cos(Θ – α), divide all terms in formula (4) by r_K and, taking into account that γ = Θ – α, we get:

$$0{,}15 \sin\alpha + 0{,}15 \sin\alpha \times \cos(\Theta - \alpha) + \sin\alpha \times \sin(\Theta - \alpha) = \\ = \cos\alpha + \cos\alpha \times \cos(\Theta - \alpha) + 0{,}06051$$

Considering that $\cos\Theta = \frac{\delta}{r_K}$; $\sin\Theta = \frac{\sqrt{r_K^2 - \delta^2}}{r_K}$; $\cos\alpha = \frac{R_{Ш,О,} - \delta}{R_{Ш.О.} + r_K}$; $\sin\alpha = \sqrt{1 - \cos^2\alpha}$, we solve the equation for δ. For the calculation, we introduce the following assumptions:

$R_{Ш.О} = 251$ mm $R_{Ш.О} = const$; $r_{K\max} = 2{,}0051$ mm; $r_{K\max} = 1{,}9949$ mm.

The calculations performed allowed us to obtain the values:

δ = – 1,9955929 mm; Θ = 3,0446837 rad; r_K = 2,0051000 mm.

The studies performed have shown that the faulty state of the hydraulic cylinder head attachment unit depends on the $F^{В}_{ИН}$ value, and also depends on the size of the attachment unit parts, when the size of the groove in the heel is less than the diameter of the retaining ring, the retaining functions of the retaining ring are minimal.

When the value of δ is close to $r_К$, found in the structures of the hydraulic cylinder assembly, the locking properties of the retaining ring increase. However, even a small value of the available inertial forces will push the ring out of the groove in the attachment point.

In order for a malfunction to occur in the attachment point of the hydraulic cylinder, the recess material is crushed by a retaining ring, which has better thermal properties than the material of the support heel.

Energy A required to crush the groove material i.e. the change in the shape of the groove is equal to:

$$A = A_Д V \ ,$$

where $A_Д$ is the energy required for deformation of a unit volume of metal, N;

V is the volume of deformable material, m3.

$$A_Д = \frac{[\sigma_{СЖ}]_{ПР} E}{2} = \frac{[\sigma_{СЖ}]^2_{ПР}}{2}$$

where $[\sigma_{СЖ}]_{ПР}$ – ultimate minimum stress at which plastic deformation of the metal occurs;

E – elastic modulus.

It is accepted:

$$E = 0{,}221 \cdot 10^6 \text{ , mpa}$$

$$[\sigma_{СЖ}]_{ПР} = 15.51 \cdot 10^2 \text{ , mpa}$$

$$V = 0{,}281 \text{ m}^3,$$

$$A_Д = 54{,}541 \text{ mpa}$$

Hence, the quantity $A = 54{,}541 \times 0{,}28 = 15{,}271$ mpa

In this case, the inertial force arising in the attachment point is equal to:

$$F_{IN}^{B} = \frac{A}{\Delta h} = \frac{15.271}{0.0151} = 1018{,}0$$, H

where A is the work performed in the attachment point in the hydraulic cylinder, mpa

Δh - the value of the relative movement of the fastening elements to the node, m.

The value $\Delta h = 0{,}0151$ m.

A malfunction of the hydraulic cylinder attachment unit of the hydraulic drive of the platform can also occur at lower values of inertial forces, i.e.

$$F_{ИН}^{B} = \frac{A}{\sum_{i=1}^{n} \Delta h_i}$$

where Δh_i is the value of the "i" movement of the mating elements, m;

n is the number of movements of the mating parts, units.

The author sees that one of the solutions to the problem of the attachment point malfunction is the replacement of the ball bearing of the hydraulic cylinder with an ear assembly developed in the developed hydraulic cylinder.

This solution is implemented in the proposed hydraulic drive of the tipping device of the platform of agricultural transport equipment, a telescopic multi-section hydraulic cylinder with a rod fixing mechanism - a mechanical ball lock. Due to the presence of a mechanical lock in the hydraulic cylinder, in the event of a leakage of the hydraulic drive, the mechanical ball lock will not allow the platform to lower onto the frame of the agricultural transport vehicle because the lock automatically locks the platform in the raised position (Figure 19) [9, 21, 22, 31].

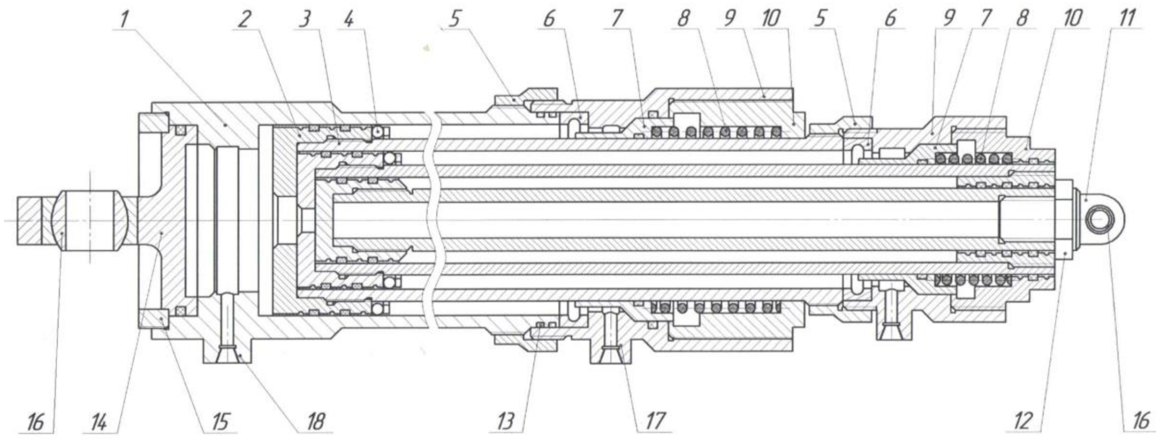


Figure 19 - Diagram of a hydraulic power cylinder:

1 – case; 2 – stock; 3 – piston; 4 – balls of a mechanical lock;

5 – connecting nut; 6 – lock ring; 7 – spacer cylinder;

8 – spring; 9 – locking cylinder; 10 – guides; 11 – ear node

The power hydraulic cylinder is a double-acting hydraulic cylinder, in which the release and removal of the rods is carried out by the hydraulic drive of the hydraulic machine and consists of a body 1, a rod 2 made of telescopic sections; a piston 3 is attached to one of the ends of each section. eight through holes, forming separators with seats for balls, from falling out of the seats inside the piston cavity, the balls are held by the outer surface of the rod section, from falling out from the piston, the balls are held by the inner surface of the cylindrical body or the inner surface of the rod sections (for balls of subsequent sections. Figure 20).

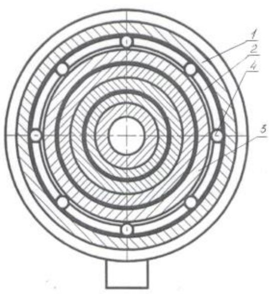


Figure 20 - Separator diagram: 1 – body; 2 – piston; 3 – stock; 4 – balls

The balls 4 have a certain degree of freedom to move in the seats. The design of the hydraulic cylinder also has connecting nuts 5, lock rings 6, spacer cylinders 7, springs 8, locking cylinders 9, guide sections of the cylinder rod 10, ear units 11, 14, spherical hinges 16. Assembled separator, spacer and locking cylinders make up a mechanism fixation. To ensure alignment, during installation, relative to the attachment points of the frame and the dump platform, the lug assembly 11 fixes the lock nut 12 from turning, the lug assembly 14 is securely pressed against the annular protrusion of the cylinder body with a threaded nut 15. For tightness of the connections, rubber sealing rings 13 are used.

Power hydraulic cylinder works as follows. To extend the rods, the working fluid through the fitting 18 is fed into the under the piston cavities, in which the pressure begins to increase, while the sections of the piston rod begin to extend. When the piston is extended, the balls 4 fit and abut against the circular tapered ledge of the end of the spacer cylinder 7. A horizontal component arises from the force of pressing the balls to the tapered part of the spacer cylinder, under the influence of which the spacer cylinder, compressing the spring 8, moves towards the cylinder cavity connected to the drain, in this case, the balls will be installed opposite the spherical groove of the lock ring 6 and under the action of the vertical component of the force of pressing them against the tapered part of the spacer cylinder, they will be pushed out of the separator seats into the annular groove of the lock ring 6, and the spacer cylinder 7, under the action of the force of the spring 8, will slip under the balls, the mechanical ball lock will close (figure 21).

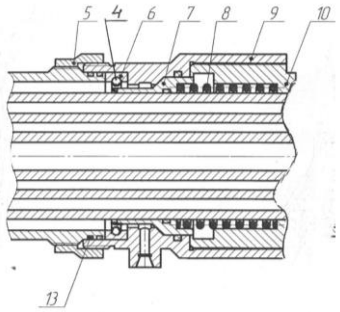


Figure 21 - Scheme of the ball lock in the closed position

To open the lock, the working fluid enters the cavity (rod sides) through the fitting 17. In an isolated chamber, between the piston and the spacer ring, an increasing pressure arises, which cannot move the piston closed to the ball lock, but compressing the spring moves the spacer cylinder to the right.

As soon as the balls of the lock are not held in the spherical groove of the lock ring by the spacer cylinder, the balls move inside the cage and open the ball lock, after which the piston will begin to retract into the cylinder body.

With the help of fastening bolts, through spherical hinges, the power gas cylinder is attached to the fastening brackets on agricultural transport equipment with ear units.

A model of a hydraulic power cylinder with a platform fixing mechanism - a mechanical ball lock, is shown in Figure 22.

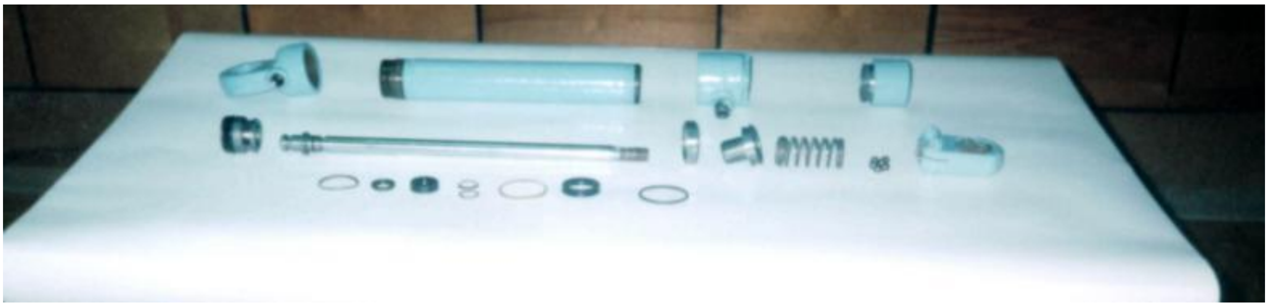


Figure 22 - Disassembled power hydraulic cylinder

To test the operability of the ball lock, a mock dump platform with a hydraulic drive was made, where an experimental hydraulic cylinder became a power element (Figure 22). To test the operability of the mechanical ball lock, its reliability, an emergency situation was simulated on a mock dump platform, in the form of a break in the hydraulic hose of the hydraulic drive. The emergency situation provided for an unauthorized (emergency) lowering (fall) of the platform [9, 21, 22, 30].

1000 emergency situations (N) were simulated. The ball lock failed to fix the platform model in only two cases. Research has confirmed the reliable operation of the mechanical ball lock

The probability of failure-free operation of the hydraulic cylinder in the experimental version is determined by the formula:

$$P = \frac{n}{N} = \frac{998}{1000} = 0.998$$

where n is the number of situations with trouble-free operation of a mechanical ball lock;

N - the total number of simulated emergency situations.

From the calculation, we see that the probability of failure-free operation of the lock is p = 0.998.

As the test of the prototype showed, the failure in operation was associated with the impossibility in laboratory conditions to ensure the necessary precision in the manufacture of parts of a mechanical ball lock.

It is believed that the industrial production of the developed hydraulic cylinder will significantly increase the reliability of the ball lock.

To protect the operator with a distance, we offer a hydraulic tipping device shown in Figure 23.

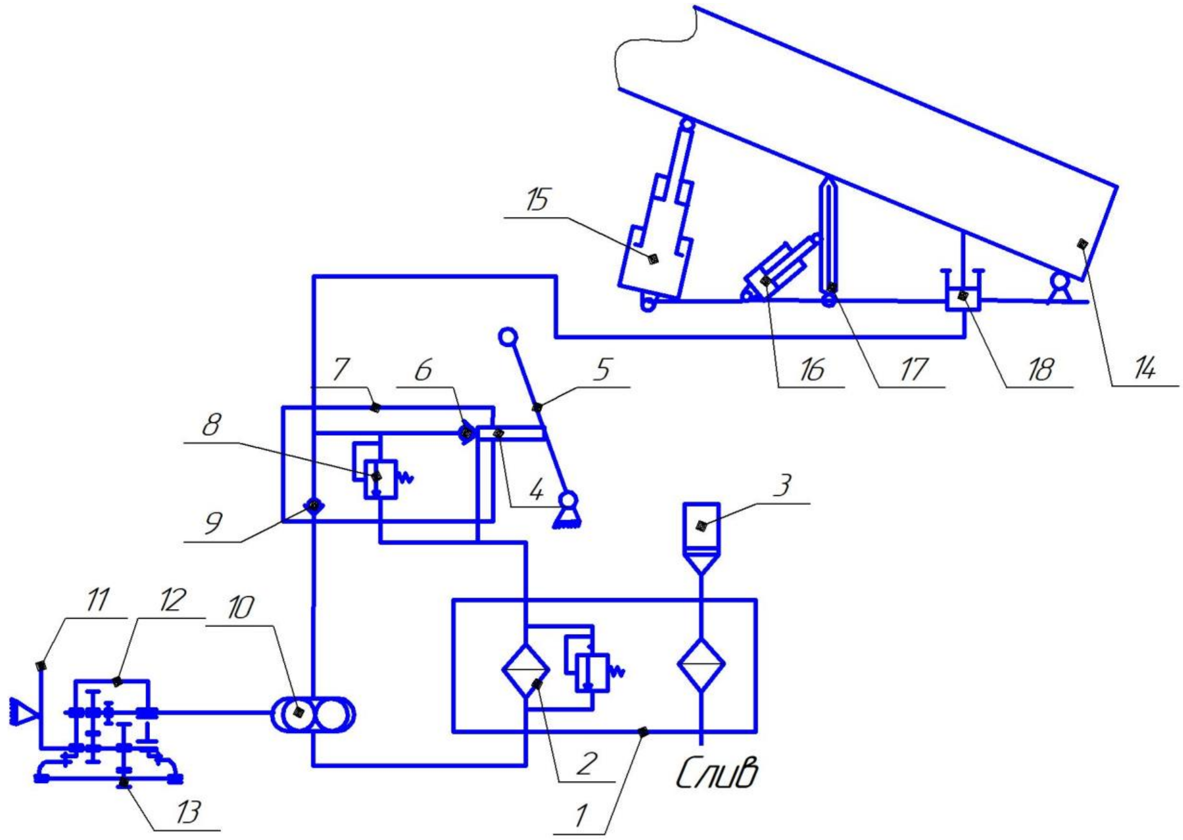


Figure 23 - Hydraulic tipping device:

1 – oil tank; 2 – drain strainer with a safety valve; 3 – filler neck; 4 – pushers of the platform lowering valve; 5 – control lever of the box of the car – dump truck; 6 – platform lowering valve: 7 – control valve; 8 – safety valve of the control valve; 9 – check valve; 10 – gear pump; 11 – power take-off control lever; 12 – power take-off box; 13 – gear wheel of reverse gear of the car gearbox; 14 – dump platform; 15 – single-acting telescopic cylinder; 16 – hydraulic cylinder; 17 – safety stop; 18 – control valve.

The hydraulic tipping device for agricultural vehicles of the GAZ - SAZ brand consists of units used on modern dump trucks.

Additionally, the standard circuit of the tipping device is equipped with: a control valve 18, which provides a sequence of hydraulic fluid supply to the hydraulic cylinders 15 and 16; safety stop 17, hydraulic cylinder 16 which provides automatic installation of the stop 17 on the heel 7 (Figure 24).

In the retracted position of the cargo dump platform, the safety stop 14 is in the retracted position. To raise the platform, the oil pump is turned on and the hydraulic fluid from the oil tank will begin to flow through the suction line into the oil pump, and from there, under pressure, through the first open channel of the distributor valve 16, into the telescopic multi-section hydraulic cylinder 15. When the platform is lifted, to the calculated angle, the first open channel the control valve 16 closes, bypassing the hydraulic fluid through the second channel, into the hydraulic cylinder 18, the automatic lifting of the safety stop 14 begins.

To lower the cargo dump platform, hydraulic fluid is fed through the second channel of the matching valve to the hydraulic cylinder 18, which begins to retrace, moving the hinge of the safety stop to the left, when the calculated angle is reached, the second open channel of the matching device 16 is closed, the first channel opens, allowing hydraulic fluid from of the telescopic multisection hydraulic cylinder 15 enter the hydraulic tank. The sections of the hydraulic cylinder begin to retrace, the dump platform sits on the frame of the dump truck.

The scheme of the safety stop of the cargo dump platform is shown in Figure 24.

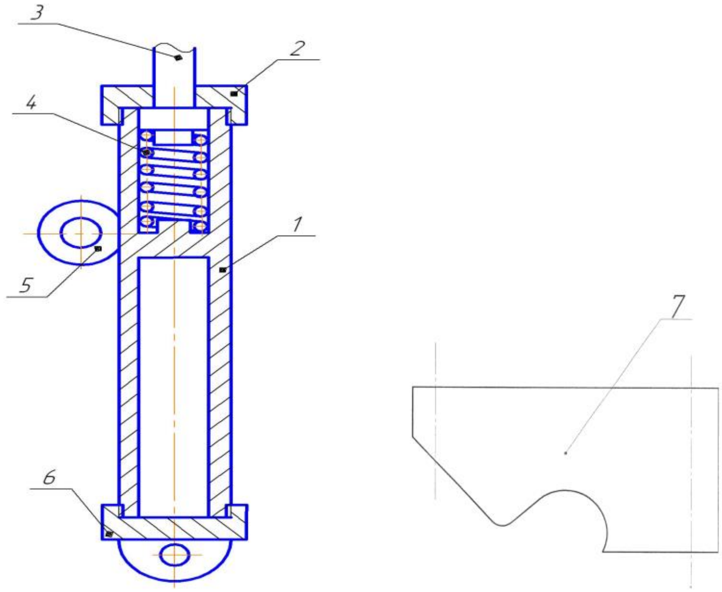


Figure 24 - Safety stop of the cargo dump platform

Safety stop for a car body – a dump truck, a loading platform of two-axle cargo tractor dump trailers, consisting of a hollow body with a partition 1, the body is closed on both sides by covers 2 and 6. The cover has a unit for attaching the stop to the car or trailer frame. Inside the body there is a retainer 3 and a spring 4. The safety stop has a unit 5 for fastening the hydraulic cylinder of the hydraulic drive [1, 28, 29].

The safety stop performs its function as follows. In the initial state, the safety stop is located under the body or load platform in the retracted position. When the body or the load platform is raised, the matching valve of the hydraulic drive of the body or the load platform is triggered, the working pressure begins to flow into the hydraulic cylinder of the hydraulic drive, the safety stop begins to rise, overcoming the resistance of the spring 4, the retainer 3 will take place in the recess of the heel 7 (Figure 2). Foot 7 is bolted to the body and (or) cargo platform.

When removing the body, the load platform, the working pressure from the control valve of the hydraulic drive is supplied to the hydraulic cylinder of the hydraulic drive, the safety stop begins to retract, while the retainer 3 comes out of the recess of the heel 7, the body and the load platform are lowered freely.

At the moment of providing technological operations of lifting – lowering, body or cargo platform, the operator is in the cab, outside the danger zone under the platform, while ensuring his complete safety.

Conclusion.

As a result of research:

1. It has been established that more than 95% of vehicles in the agro-industrial complex are equipped with a hydraulic drive, which, despite its advantages, has a number of design and production disadvantages associated with ensuring the tightness of the joints.

2. It has been proven that the most dangerous sources of injury to operators are cars - dump trucks and dump trailers. The main traumatic situation is associated with pressing down the operator by spontaneously lowering loading platforms, the cause of which is a hydraulic drive malfunction (48%).

3. It is substantiated that the safety and locking devices currently used in hydraulic drives of vehicles do not fully fulfill their functions. At maximum load (from the instruction manual), even with standard retarding valves, the lowering speed of the tipper platforms becomes unacceptably high. Operator safety is the dominant factor in the consequences of a hydraulic drive failure.

4. Experimental studies of systems to prevent unauthorized (emergency) lowering (falling) of platforms of transport and mobile energy facilities allow one to conclude on their operability and efficiency, the developed technical safety equipment for dump platforms ensure the safe operation of the operator with a probability equal to 0.98.

Thus, the studies carried out and the conclusions drawn allow us to conclude the following:

1. The relevance of the study is due to the alarming indicators of injuries of operators of transport and mobile energy vehicles used in agricultural production, most accidents occurred due to constructive production flaws in equipment, in particular, dump trucks, dump trailers with a hydraulic tipping device.

In this regard, this article is aimed at identifying the causes of the factors and circumstances of accidents of agricultural machinery operators, whose injuries end in serious or fatal outcomes, and the operators were injured as a result of unauthorized (emergency lowering (falling) of cargo dump platforms).

The leading approach to the study of this problem has become an integrated approach that makes it possible to systematically consider the causes of injuries, identify the culprits, develop measures and give recommendations to reduce the number of people injured in agricultural production, and to reduce the severity of the consequences of accidents.

The article discloses the reasons for the unauthorized (emergency) lowering (falling) of the dump platform, a mathematical model of the reason has been developed that allows us to state that the fasteners of the hydraulic cylinder power unit, made in the form of an O-ring and a groove, are not capable of performing locking functions under the them axial loads. The value of the axial load on the retaining ring, which can lead to instant disconnection of the hydraulic cylinder attachment unit, is calculated, equal to 1018.0 N, it is substantiated that the developed device for regulating the fluid flow rate in the hydraulic drive provides a constant time for lowering the platform regardless of the external load. The results of experimental studies confirmed its performance, the discrepancy between the actual t_a = 54.1 sec. and estimated t_e = 56.4 sec. of the platform lowering time does not exceed 2.3 sec, i.e. 4.25%, new technical means of safety for dump platforms have been developed, studies have proven their efficiency, in particular, a mechanical ball lock installed in the developed power telescopic three-section hydraulic cylinder of a double-acting hydraulic tipping device of a dump platform, ensures its fixation in a raised position with a probability equal to 0.98.

The materials of the article are of practical value for the transport industry, employees of research institutes and universities, heads of agricultural enterprises and all interested parties (masters, graduate students, engineers).

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