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RESEARCH AND DEVELOPMENT OF THE STRUCTURES OF HIGHLY LOADED BUNTON DAMPERS TO DECREASE DYNAMIC EFFECTS IN THE "VEHICLE–REINFORCEMENT" SYSTEM

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Abstract. The authors study the horizontal loads arising from the movement of vehicles under the action of dissipative forces (torsion of ropes, aerodynamic forces, loading the vehicle with eccentricity in the frontal and lateral planes) which act on rope-profile guides (hereinafter referred to as RPGs or guides). The structures of damper buntons are developed that reduce vibrations by the interaction of guides with damper elements of buntons of various structures, which are located at the meeting point of vehicles and further along the shaft. The step of limiting buntons at the meeting point of vehicles in the middle part of the shaft has minimum value, and then the step increases stepwise and further remains constant. A kinematic connection of the RPG and the bunton in the form of a bunton leg and connecting inserts is developed, which allow the guide to move up and down and bend to a safe amount in the frontal and lateral directions; then the horizontal load is damped with the help of bunton dampers and the bunton structure. Console buntons, located along the shaft depth with a constant step, are equipped with dampers, which consist of rubber inserts with soft metal plates, assembled using bolted connections on a console bunton. At the meeting point of vehicles in the middle part of the shaft, the console bunton dampers have a more complex structure and consist of shock absorbe rs built into the box-shaped bunton which rod is built into the bunton leg, which moves in the guides and damps the load. Bunton dampers consist of a shock absorber and a built-in pneumatic cylinder and have a greater absorbing effect. The development of various structural solutions for buntons with dampers for different shaft sections and a kinematic connection for a bunton operation with rope-profile guides makes it possible to achieve:

– high reliability during RPG operation;

– increased service life due to a significant decrease in the level of dynamic effects;

– reduced labor intensity of maintenance and operation, compared to rigid reinforcement;

– reduced metal consumption compared to rigid reinforcement.

Keywords: mine vertical shafts, rope-profile guides, console-damper buntons, pneumatic cylinder, shock absorbers, draft gears, frame buntons, horizontal forces in the frontal and lateral directions.

1. Introduction

Vertical shafts are the main workings of the mine, ensuring the functioning of all transport systems of the mine, as well as ventilation of mine workings, power supply and other communication processes necessary for the life of the underground part of the mining enterprise.

For directional movement of vehicles, vertical shafts are equipped with guides: rigid and flexible. Rigid guides are fixed on horizontal buntons (rigid reinforcement), flexible guides (rope guides) are fixed in a headframe and hang along the entire depth of the shaft (flexible reinforcement), tightened with tension weights located in the sump part of the shaft.

When vehicles move in guides of rigid reinforcement under the influence of:

– loading of vehicles with eccentricity;

– aerodynamic resistance;

– torsion of ropes;

– deflection of guides from the vertical (as a result of installation, the influence of rock pressure, etc.);

– periodically changing stiffness of guides;

– the curvature of the guides, the horizontal dissipative forces arise acting on the reinforcement.

The calculation and design of rigid reinforcement is carried out in accordance with the standard procedure [1]. Rigid reinforcement has high reliability and durability, but it also has significant disadvantages:

– high metal consumption;

– significant labor intensity in maintenance and repair;

– high labor intensity of installation;

– high corrosive wear of fasteners and metal buntons;

– bending of guides in case of violations of the shaft lining as a result of rock pressure;

– a large number of bolted serviced connections;

– significant aerodynamic resistance of the air stream, increasing along the shaft depth.

Flexible reinforcement has a constant rigidity of guides along the shaft depth, but in comparison with rigid reinforcement it has low torsion and bending rigidity, which leads to torsion of vehicles during their movement. Therefore, according to the method [2], to prevent collision of vehicles when they meet in the middle of the shaft, safety gaps of 350 mm per side are provided for skip hoists and 500 mm per side for cage hoists along the entire depth of the shaft, which leads to a significant increase in the shaft diameter and capital costs during construction.

In addition, flexible reinforcement has other disadvantages:

– low service life of rope guides, which is not more than 4 years;

– the need to use fender ropes;

– a large number of tension weights in the sump.

There are console reinforcements, where console buntons are used instead of buntons through the entire cross section of the shaft. This makes it possible to reduce the aerodynamic resistance of the shaft, but increases the metal consumption of the buntons because of the need to keep the own weight of the guides on the consoles [9].

In the proposed structure of reinforcement, where ropes in the guard profile are used as guides, the so-called rope-profile guides (hereinafter referred to as RPGs or guides), it has been achieved a reduction in the impact of the above disadvantages of existing reinforcements.

2. Methods

The research is based on the objective to develop structures reducing the level of dynamic interaction in the "vehicle–reinforcement" system, and reducing the level of horizontal forces at the meeting point of vehicles in the middle part of the shaft. The research and development of the structures resulted in the ability to achieve the following:

– to ensure high reliability of operation and service life of damper buntons;

– to ensure significant damping of horizontal loads that occur during the emergency mode of movement of vehicles;

– to ensure a long trouble-free service life of RPGs;

– to reduce the labor intensity of reinforcement maintenance and operation;

– to reduce the level of dynamic oscillations in the "vehicle–reinforcement" system;

– to increase the reliability of the kinematic connection in the "vehicle–reinforcement" system.

3. Results and discussion

RPG ropes are fixed at the top of the shaft in the headframe and hung along the shaft depth. Preload is provided using damping tension weights located in the sump part of the shaft [2] or tension weights in multiple groove pulleys located in the shaft headframe.

When the vehicles move along the shaft depth in the RPG under the influence of various factors, namely: – torsion of the head ropes; – loading vehicles with eccentricity; – aerodynamic forces at the meeting point of the vehicles, horizontal forces arise in the "vehicle–reinforcement" system.

Forces acting on the RPG in the frontal direction:

$$P_{frontal}^{total} = P_{frontal}^{eccentricity} + P_{frontal}^{torsion} + P_{frontal}^{aerodynamic}; N$$, [1, 2, 3, 4, 5, 6, 8, 9]

Forces acting on the RPG in the lateral direction:

$$P_{lateral}^{total} = P_{lateral}^{eccentricity} + P_{lateral}^{torsion} + P_{lateral}^{aerodynamic}; N$$, [1, 2, 3, 4, 5, 6, 8, 9]

The total value of dissipative forces arising from the movement of vehicles at maximum speed along the shaft depth under the action of a combination of the most unfavorable factors is approximately: 5-10 kN in the frontal direction and up to 2 kN in the lateral direction.

Using the finite element method in the ANSYS 17.1 program, we determine the values of frontal deflections (as the most dangerous ones) for rope guides and RPGs when a static load of 10 kN is applied.

Under the constant static horizontal load, the values of RPG deflections reach 47 mm in the middle of the span H=60 m between fencing buntons, but since the vehicle moves in the RPG with the help of safety legs with grippers 6 and flanged fencing rollers 2.2 (see Figures 3 and 4), then the total deflection of the two guides is 47/2=23.5 mm, because one vehicle moves in two RPGs (see Figure 1).

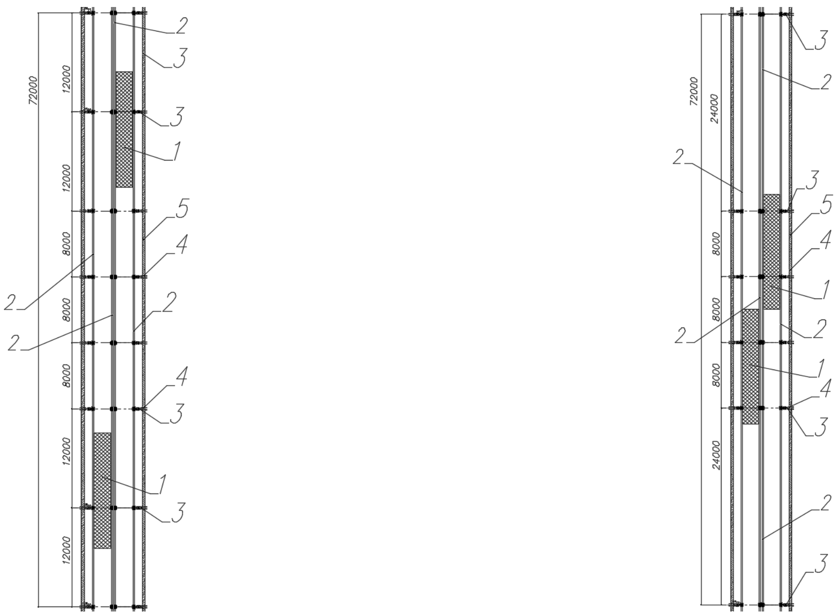
When the vehicle moves, the horizontal load generated by it is not static, but varies depending on the coincidence of various factors, namely:

– the degree of loading vehicles with eccentricity;

– torsion of ropes;

– aerodynamic forces, and as a result the maximum value is 10 kN and acts for a short time on the RPG when the vehicle moves along the shaft depth.

The deviation of the vehicles during their movement in the RPG by the value of 23.5 mm is not critical, however, at the meeting point of vehicles in the middle part of the shaft, in order to increase the safety level, the installation step of fencing console buntons is reduced [5]. Fencing console buntons are understood as console buntons, which are not affected by the RPG weight, but which serve to reduce the angles of vehicle rotation, kinematic connection and reduce the level of dynamic effects in the "vehicle–reinforcement" system.



a b

a – reinforced; b – lightweight

1 – vehicle; 2 – RPG; 3 – bunton; 4 – fastening anchor; 5 – shaft lining

Figure 1 – Discrete reinforcement with RPG

Therefore, at the meeting point of moving vehicles in the middle part of the shaft, fencing (damping) buntons are installed with a discrete step according to the following scheme: three spans 8 m long, then two spans with a step of 12 m on each side (see Figure 1a) or 24 m on each side (see Figure 1b), and further – 60 m on both sides. Let us represent discrete step by the following schemes: 60-24-8-8-8-24-60 and 60-12-12-8-8-8-12-12-60 the first scheme is intended for low values of dissipative forces, and the second for high values [10].

For a discrete step of the RPG at the meeting point of the vehicles (see Figure 1), we use the finite element method in the ANSYS 17.1 program to determine the values of frontal deflections (as the most dangerous) for flexible reinforcement and a RPG consisting of 6 ropes d=42 (GOST 7669-80) with a steel core and fencing profile consisting of a C-channel 200×180×8 (GOST 8278-83) and a back cover 4 mm thick, when applying a static load of 10 kN, and summarize the obtained values in Table 1.

As can be seen from the results of Table 1, the values of total deflection of the guides under the most unfavorable combination of factors at the meeting point of the vehicles are acceptable – 2 mm and 4 mm.

Obviously, the RPG deflection by 23.5 mm in the span H=60 m occurs in the middle of the span, and closer to the console bunton it will be much less, however, given that the vertical shaft is a particularly important structure, in order to increase the safety level and increase the damping properties of buntons, we suggest structural solutions for strengthening the damping of horizontal forces on the bunton.

Table 1 – Comparative table for determining deflections when applying a static horizontal load of 10 kN

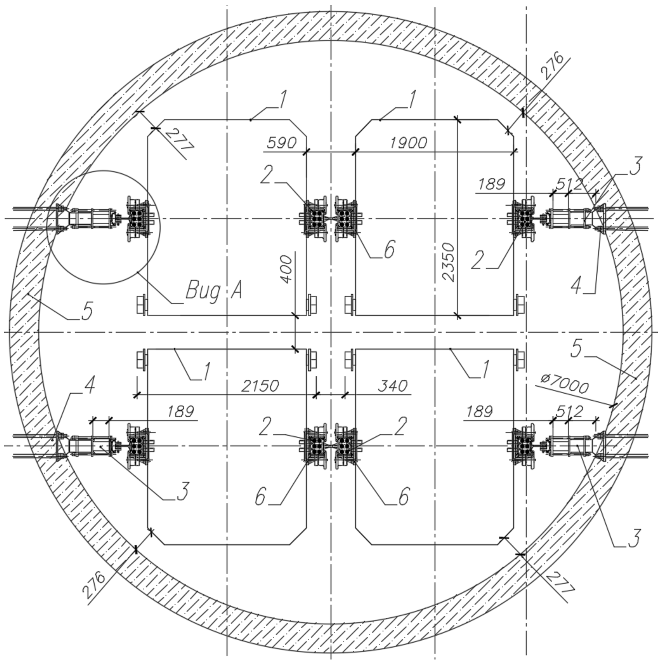
No.	Name	Unit	4 rope guides per vehicle d=52	2 RPGs per vehicle (6 × d=42)
1	Rope guide deflection in the middle of the shaft	mm	917.25/4=229.25	
2	Guaranteed gap between vehicles Δ	mm	50	50
3	Guide deflection at a step of 8 m	mm	–	4/2=2
4	Guide deflection at a step of 12 m	mm	–	8/2=4
5	Guide deflection at a step of 60 m	mm	–	47/2=23.5

Figure 2 shows the layout of four vehicles (skips of the CHM 35-235-1,1 type) in the shaft, 7 m in diameter, moving in RPG 2, taking into account all the clearances required by regulatory documents [7] at the meeting point of the vehicles. The movement of vehicles in the horizontal plane is limited with the help of console buntons 3, fixed in the shaft lining 5 with the help of anchors 4, the kinematic connection of the vehicle with the guide is carried out using rollers and safety legs 6.

Figure 3 (View A) shows a console bunton 3, which is connected with the RPG into a single system by means of an intermediate structure 2.2.

Instead of rubber dampers, a shock absorber (pneumatic shock absorber or hydraulic shock absorber) is installed on the console bunton 3, which (see Figure 3) is fixed with the help of anchors 4 in the shaft lining 5. Attachments of guides 3.2, in which bolted guides 3.10 move rigidly fixed in the bunton leg attachment 3.3, are installed on the bunton. The bunton leg 3.6 with interchangeable inserts 3.6.1, which provides a kinematic connection between the bunton and the RPG using a section of rail 2.2, is installed on the attachment 3.3. The rail section 2.2 is fixed with the help of bolted connections 2.3 in the clamping bracket 2.5 of the RPG 2, which allows the RPG to move up and down and left and right, within the gaps and not lose the kinematic connection with the bunton 3.

The movement of the vehicle 1 in guides 2 is carried out with the help of rolling guide rollers installed on the vehicle: – a flange fencing roller 7.1, providing a clamping force behind the rear wall of the fencing profile 2.6 of the RPG and straight rollers 7.2. In the frontal direction, the kinematic connection between the RPG and rollers is carried out using the flange of the roller 7.1 and straight rollers 7.2, and in the lateral direction, the transfer of horizontal forces from the vehicle to the guide occurs due to the straight part of the rollers 7.1 and rollers 7.2 installed on the side surfaces of the fencing profile 2.6 of the RPG (see Figures 3 and 4). To increase the reliability of the kinematic connection of the vehicle in the lateral direction, in addition to the main roller guides installed on the cover and at the bottom of the vehicle, the guides are installed along the vehicle length [8]. To increase reliability, rigid safety legs are installed on the vehicle having grips behind the RPG with replaceable inserts 6.1 that reduce leg abrasion.



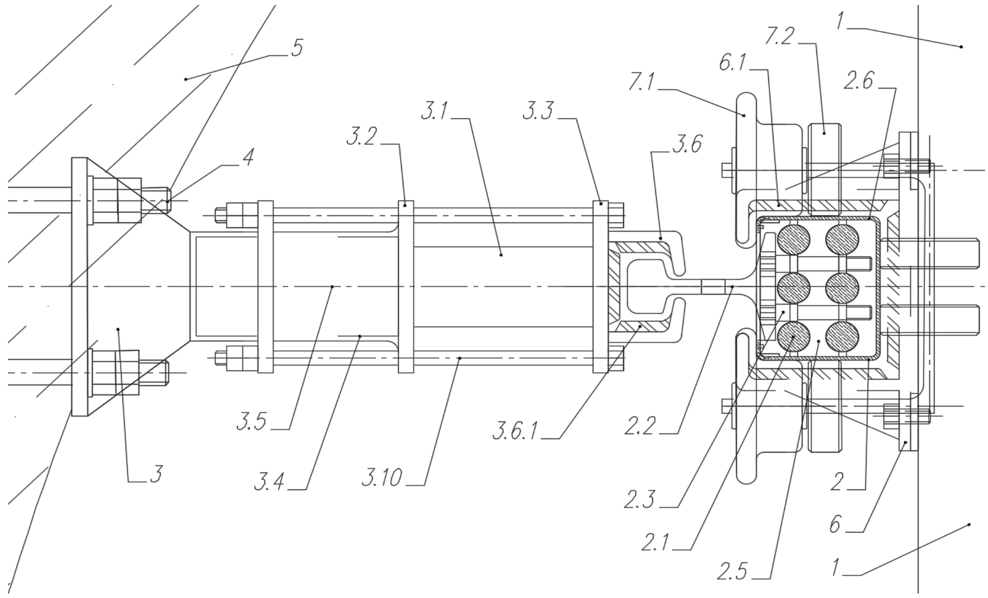
1 – lifting vehicle (skip СНМ 35-235-1,1); 2 – RPG; 3 – console bunton; 4 – anchors; 5 – shaft lining; 6 – safety leg

Figure 2 – Cross-section of the shaft with four coal skips and console buntons, equipped with pneumatic cylinders

Figure 4 (view A1) shows a similar structure of a damper bunton, working with RPG. This structure differs from the above structure (see Figure 3) by the presence of an additional pneumatic shock absorber 3.1.1 (made as a pneumatic cylinder) mounted on the shock absorber rod 3.1, which significantly increases the force and reliability of damping in the frontal plane.

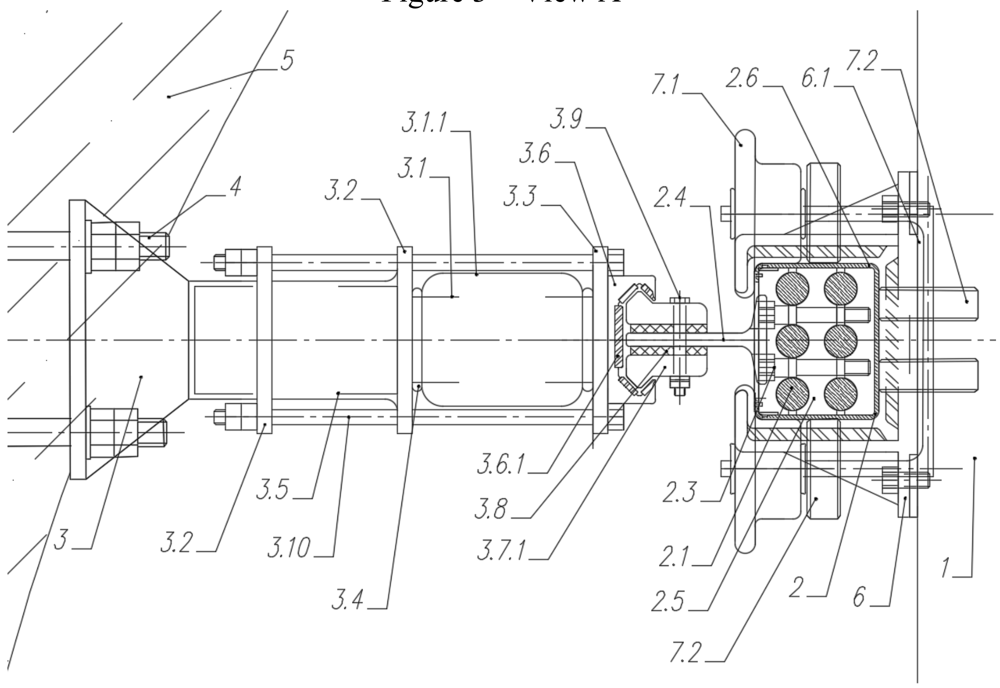
To improve the connection of the RPG with the bunton, a bunton leg was developed in the form of triangular grips 3.6, in which the connecting inserts 3.7.1 move, fixed on the lifting rail without a head using bolt fasteners 3.9 along the length. Rubber dampers 3.8 are installed between the connecting inserts 3.7.1 to increase damping of vibrations in the lateral plane, but since the values of the horizontal forces in the lateral plane are much less than in the frontal plane, these dampers are much smaller. The above structure has a lower weight compared to the rail 2.2 (see Figure 3), connecting inserts 3.7.1, when abraded, are easily removed and replaced with new ones without disassembling the RPG coupling bracket, which makes it possible to make the lifting rail 2.4 longer and provide safe gaps between the roller flange 7.1, the safety leg 6 and inserts 3.7.1.

The grip of the leg 3.6, made in the form of triangles, allows to hold and restrict the RPG rotation within the gaps (6 mm) of the bunton leg, due to its length and large contact area between the leg and the connecting inserts, which reduces dynamic interaction and ensures the strength and reliability of the kinematic connection of RPG and bunton. Such structures of damper buntons, described above and shown in Figures 3 and 4, can be used along the shaft depth in the area of movement of vehicles at a constant speed.



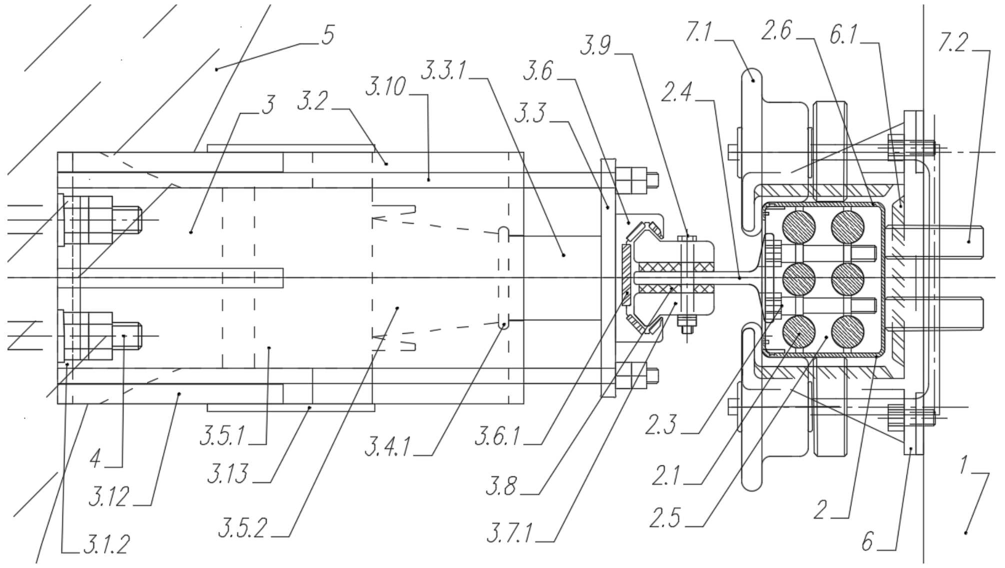
1 – lifting vehicle (skip CHM 35-235-1,1); 2 – RPG; 2.1 – rope; 2.2 – attachment rail; 2.3 – tightening bolts of the RPG; 2.5 – clamping bracket; 2.6 – fencing profile of the RPG; 3 – console bunton; 3.1 – shock absorber rod; 3.2 – attachment of guides; 3.3 – attachment of the bunton leg; 3.5 – shock absorber sleeve; 3.6 – bunton leg; 3.6.1 – bunton leg inserts; 3.10 – bolt guides; 4 – anchors; 5 – shaft lining; 6 – safety leg of the RPG; 6.1 – safety leg inserts; 7.1 – fencing roller; 7.2 – straight roller

Figure 3 – View A



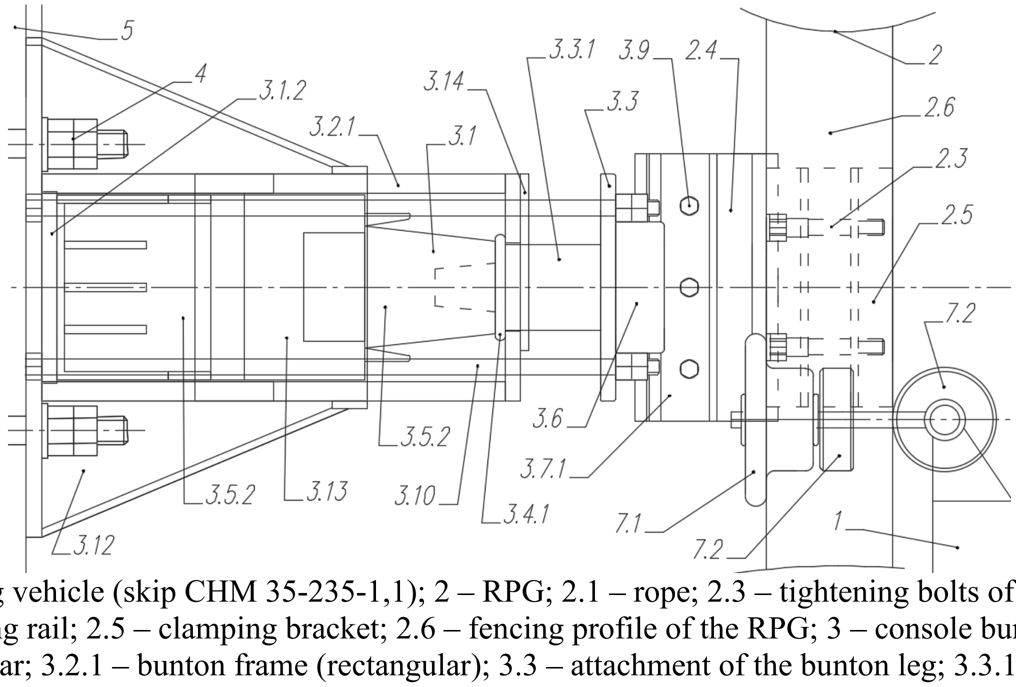
1 – lifting vehicle (skip CHM 35-235-1,1); 2 – RPG; 2.1 – rope; 2.3 – attachment rail; 2.4 – lifting rail; 2.5 – clamping bracket; 2.6 – fencing profile of the RPG; 3 – console bunton; 3.1 – shock absorber rod; 3.1.1 – pneumatic damper; 3.2 – attachment of guides; 3.3 – attachment of the bunton leg; 3.4 – washer of the attachment; 3.5 – shock absorber sleeve; 3.6 – bunton leg; 3.6.1 – bunton leg inserts; 3.7.1 – connecting inserts; 3.8 – rubber damper; 3.9 – bolt fastening; 3.10 – bolt guides; 4 – anchors; 5 – shaft lining; 6 – safety leg of the RPG; 6.1 – safety leg inserts; 7.1 – fencing roller; 7.2 – straight roller

Figure 4 – View A1



1 – lifting vehicle (skip CHM 35-235-1,1); 2 – RPG; 2.1 – rope; 2.3 – tightening bolts of the RPG; 2.4 – lifting rail; 2.5 – clamping bracket; 2.6 – fencing profile of the RPG; 3 – console bunton; 3.1.2 – guide bar; 3.2.1 – bunton frame (rectangular); 3.3 – attachment of the bunton leg; 3.3.1 – bunton leg rod; 3.4.1 – limiter of the bunton leg rod; 3.5.1 – draft gear; 3.5.2 – pressure cone; 3.6 – bunton leg; 3.6.1 – bunton leg inserts; 3.7.1 – connecting inserts (Rubel); 3.9 – bolt fastening; 3.10 – bolt guides; 3.11 – guide attachment bar; 3.12 – attachment stops; 3.13 – holding bars; 4 – anchors; 5 – shaft lining; 6 – safety leg of the RPG; 6.1 – safety leg inserts; 7.1 – fencing roller; 7.2 – straight roller

Figure 5 – View A2 (top view)



1 – lifting vehicle (skip CHM 35-235-1,1); 2 – RPG; 2.1 – rope; 2.3 – tightening bolts of the RPG; 2.4 – lifting rail; 2.5 – clamping bracket; 2.6 – fencing profile of the RPG; 3 – console bunton; 3.1.2 – guide bar; 3.2.1 – bunton frame (rectangular); 3.3 – attachment of the bunton leg; 3.3.1 – bunton leg rod; 3.4.1 – limiter of the bunton leg rod; 3.5.1 – draft gear (of PT-120 type); 3.5.2 – pressure cone; 3.6 – bunton leg; 3.7.1 – bunton leg inserts; 3.7.1 – connecting inserts (Rubel); 3.9 – bolt fastening; 3.10 – bolt guides; 3.11 – guide attachment bar; 3.12 – attachment stops; 3.13 – holding bars; 3.14 – supporting bars; 4 – anchors; 5 – shaft lining; 7.1 – fencing roller; 7.2 – straight roller

Figure 6 – View A2 (side view)

As can be seen from the discrete step (see Figure 1) and Table 1, the deflection upon reaching the maximum static horizontal load of 10 kN with a step H=60 m is 23.5 mm. Along the shaft depth, the horizontal load during the movement of the vehicle is damped due to the guide deflection and the movement of legs in the gaps, in case of greater deflection it is damped with the help of bunton dampers (rubber, pneumatic cylinders, shock absorbers, combined), and in case of emergency loads – due to impact on the box-shaped profile of the bunton.

Applying a discrete interval of reinforcement (see Figure 1) at the meeting point of the vehicles, it is possible to significantly reduce the RPG deflection (see Table 1) and the level of dynamic effects, but at the transition from one interval to another, a step is formed when the same horizontal loads are applied, the largest at the transition from H=60 m to H=12 m, i.e. 23.5 mm and 4 mm. If the horizontal load reaches 10–15 kN, then damper buntons shown in Figures 3 and 4 may be used at the meeting point of the vehicles, but for the operation under emergency loads that occur when one head rope breaks, when a safety brake is applied, etc., the bunton dampers allowing to reduce significant horizontal loads should be developed and installed in the lower and upper parts of the section at the meeting point of the vehicles.

Figure 5 shows a top view of a damper bunton, which makes it possible to damp the horizontal load in the frontal direction both when the vehicle moves towards the shaft lining and away from it in the opposite direction from the shaft lining.

The rectangular bunton frame 3.2.1, welded from sheet metal in the form of a box without side surfaces, is fixed in the shaft lining 5 (see Figure 5) with the help of anchors 4 and strengthened with triangular spacers 3.12. A draft gear (of PT-120 type, class T1) is installed in the box 3.2.1 and closed with holding bars 3.13. The kinematic connection of the RPG 2 and the bunton leg 3.6 is carried out using the lifting rail 2.4 and the connecting inserts 3.7.1 mounted on the attachment 3.3. Attachment 3.3 has the bunton arm rod 3.3.1, which protrudes into the pressure cone 3.5.2 and moves in a rectangular frame 3.2.1, the limiter of the bunton frame 3.4.1 does not allow the rod 3.3.1 to fall out of the frame 3.2.1 (see Figure 5 and 6). The attachment of the bunton leg 3.3 contains bolted guides 3.10, which are connected at the other end to the guide bar 3.1.2, which is located behind the strengthened base of the draft gear 3.5.1. Console fastening of the bunton leg 3.3 is carried out with the help of supporting bars 3.14, which support the bolt guides 3.10 and the bunton leg rod 3.3.1.

The operation of the damping bunton occurs as follows. When the RPG is deflected in the frontal direction towards the shaft lining 5, the pressure is applied to the bunton leg 3.6 through the lifting rail 2.4 and connecting inserts 3.7.1; then the rod 3.3.1 with the limiter 3.4.1 presses on the pressure cone 3.5.2, which damps the load with the help of a package of elastic elements (the structure of the draft gear is shown in Figure 7).

When the vehicle 1 moves from the shaft lining 5 with a horizontal force through safety legs 6 with grips and flanged fencing rollers 7.1, it is transferred to the RPG 2 and with the help of the lifting rail 3.4 and connecting inserts 3.7.1 on the bunton leg 3.6 fixed on the attachment 3.3, which pulls the bolt guides 3.10 and with the help of the guide bar 3.1.2, draft gear 3.5.1, moving from the lining 5 to the RPG 2, rests by its pressing cone 3.5.2 to the bunton frame 3.2.1, thus damping the dynamic load.

Depending on the horizontal forces, draft gears can be installed in various types of damping bunton structures. Draft gears are widely used in transport for many years, they are mass-produced by many manufacturers, and have high reliability; long warranty period; long overall service life; a wide range of temperature, humidity, and contamination modes. Classification of draft gear types is given in Table 2.

Table 2 – Classification and service life of draft gears

<table>
<tr><th>No.</th><th>Model</th><th>Class</th><th>Type</th><th>Manufacturer</th><th>Structural stroke, mm</th><th>Rated power capacity in kJ for the force of 2MN</th><th>Guaranteed service life, years</th><th>Service life before overhaul, years</th><th>Total service life, years</th><th>Notes</th></tr>
<tr><td>1</td><td>Ш-1-ТМ</td><td>Т0</td><td rowspan="5">Friction</td><td rowspan="4">Not produced</td><td>70</td><td>20</td><td rowspan="4">2</td><td rowspan="4"></td><td rowspan="4">8</td><td rowspan="5">Exceptional cases when going to repair</td></tr>
<tr><td>2</td><td>Ш-2-Т</td><td>Т0</td><td>110</td><td>65</td></tr>
<tr><td>3</td><td>Ш-2-В</td><td>Т0</td><td>90</td><td>40</td></tr>
<tr><td>4</td><td>Ш-6-ТО-4</td><td>Т0</td><td>110</td><td>65</td></tr>
<tr><td>5</td><td>ПМК-110-К-23</td><td>Т0</td><td>JSC "Bryansk Mechanical Engineering Plant" ("BMZ"), Bryansk; LLC "Production Company "Bezhitsk Steelwork" (PK "BSZ"), Bryansk; LLC "Centrolit", Barnaul</td><td>110</td><td>70</td><td>2</td><td></td><td>8</td></tr>
<tr><td>6</td><td>ПМКП-110</td><td>Т1</td><td rowspan="4">Friction with elastic elements</td><td>JSC "Bryansk Mechanical Engineering Plant" ("BMZ"), Bryansk; LLC "Altaivagon"; LLC "VKM-Stal", Saransk; JSC</td><td>110</td><td>70</td><td>8</td><td>16</td><td>24</td><td rowspan="3">Non-dangerous goods (platforms, open cars, covered cars, etc.)</td></tr>
<tr><td>7</td><td>АПМ-120-Т1</td><td>Т1</td><td>JSC</td><td>120</td><td>70</td><td>8</td><td>16</td><td>24</td></tr>
<tr><td>8</td><td></td><td>Т1</td><td>Suzhou East Railway Co., Ltd., China</td><td></td><td></td><td>8</td><td>16</td><td>32</td></tr>
<tr><td>9</td><td>M901E/Group J-SL-76 ™ (PT-130)</td><td>Т2</td><td>Miner Enterprises, Inc. was founded in 1894 (1200 East State Street, Geneva, IL 60134),
JSC "Azovmash" Mariupol, Ukraine</td><td>130</td><td></td><td>8</td><td>16</td><td>32</td><td>all types of freight cars, except for gas tanks</td></tr>
</table>

The main technical specifications of the draft gears most commonly used in the operation of vehicles are given in Table 2.

As can be seen from the technical specifications of draft gears given in Table 2, the most acceptable draft gears in terms of reducing the level of dynamic effects in the "vehicle–reinforcement" system are the draft gears of class T1 (MINER company, USA), which are also the most reliable, common in transport and have a wide network of service and repair enterprises.

To ensure elasticity, the friction unit in the draft gear is supported by a set of elastic elements. A feature of the friction unit, unlike other hexagonal type draft gears (such as Ш-2-В), is the presence of bronze inserts on the inner surfaces of the body in the zone of operation of wedges. These inserts play the role of a lubricant. They stabilize friction and reduce wear of friction parts. In addition, the draft gear does not have a tightening bolt, which eliminates the cases of its unscrewing and disintegration of the draft gear during operation. The guide rod is used for central compression of the elastic set. The draft gear PT-120 uses a set of TecsPak polymer elements as an elastic unit, which not subject to corrosion, pressed with a washer, three friction wedges and a pressure cone. The body has H-shaped grooves located in the zone of contact with wedges. Bronze inserts are pressed into them in order to reduce the intensity of wear of the body surfaces and wedges.

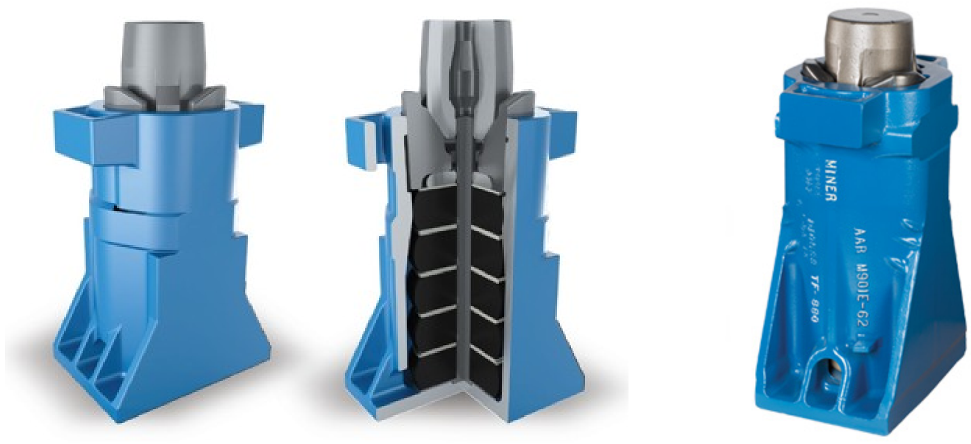


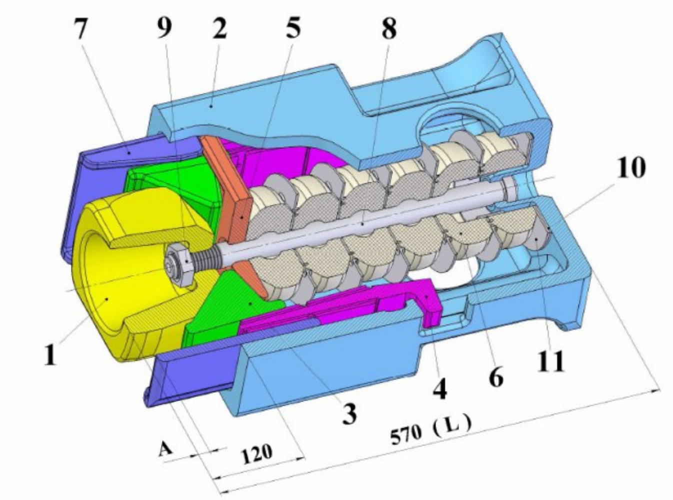
Figure 7 – Draft gear TF-880™ TecsPak® (class T1)

Technical specifications of the draft gear TF-880™ TecsPak® [11] (PT-120): power capacity - not less than 70–120 kJ; operating temperature range: -60 °C to +50 °C; structural stroke – 120 mm; guaranteed service life – 8 years; service life before the first overhaul – 16 years; total service life – 32 years; overall dimensions – 578×228×321 mm; weight – 120 kg.

The disadvantage of this TF-880 draft gear is its long running-in period after the start of operation. The advantage is its long service life and high wear resistance, the draft gear can travel with a car up to 1.8 mln km without overhaul.

The draft gear TF-880 (similar to PT-120) is widely used and mass-produced by various enterprises. This fact determines its affordable price.

An analogue of TF-880 (PT-120) produced in Ukraine is АПМ-120-Т1 manufactured by JSC, which is a mechanism of elastic-friction type developed on the basis of the draft gear ПМКП-110К-23. Instead of a spring set, it uses a package of elastic elements 6. Stabilization of the power characteristic of a package of elastic elements 6 is provided by adjusting plates 10 and plate 11. All parts in the draft gear are fixed by a tightening bolt 8 with a nut 9 (see Figure 8).



1 – pressure cone; 2 – body; 3 – wedge; 4 – fixed plate; 5 – support plate; 6 – package of elastic elements; 7 – movable plate; 8 – tightening bolt; 9 – nut M30-6H.20 GOST 5916-70; 10 – adjusting plate; 11– plate

Figure 8 – Draft gear АПМ-120-Т1 (class T1)

Figure 9 – Draft gear SL-76 (class T2) Miner Enterprises, Inc

For damper buntons in the same dimensions, the latest draft gear of class SL-76 (class T2) [11] (similar to PT-130) is suitable which structure includes a "cone-wedge-body" friction unit, as well as large and small Birchpad polymer elastic blocks operating without preload. It has a rated power capacity of one third more than TF-880 and reaches 100 kJ.

Table 3 – ST Rubber draft gear Suzhou East Railway Co., Ltd. (China). Main technical specifications of the draft gear

Operating parameters of the rubber-spring draft gear	Value
Rated power (kJ)	20
Rated impact speed (km/h)	7
Rated force of resistance (kN)	2000
Nominal travel distance (mm)	68
Absorption rate (%)	≥80
Free length (mm)	568
Assembled length on vehicle (mm)	550
Working environment	-30 °C to 50 °C

Table 4 – Rubber draft gear, Suzhou East Railway Co., Ltd. (China). Main technical specifications of the draft gear

Operating parameters of the cement-spring draft gear	Value
Rated power (kJ)	40
Impact (t)	120
Rated force of resistance (kN)	2000
Nominal travel distance (mm)	50
Absorption rate (%)	≥60
Free length (mm)	345
Assembled length on vehicle (mm)	333
Working environment	-30 °C to 50 °C

Table 5 – UIC draft gear (buffer), Suzhou East Railway Co., Ltd. (China). Main technical specifications of the draft gear

Type	Capacity	Stroke	Reaction force	Buffer type	Nominal capacity
UIC	≥40 kJ	110±10 mm	≤800 kN	Steel friction and rubber	≥80%

In view of the armed aggression of the Russian Federation against the state of Ukraine, started on February 24, 2022, many manufacturing enterprises fell under temporary occupation and suffered significant damage (JSC "Azovmash", Mariupol and many others), so the use of draft gears of PT-120, PT-130, and АПМ-120 types became possible from warehouse residues, therefore, it is preferable to use draft gears manufactured by Suzhou East Railway Co., Ltd. (China) [12] and MINER (USA) [11].

According to the above, the maximum horizontal force, aroused when vehicles, moving in rope-profile guides, meet in the middle of the shaft, is 10 kN. The use of draft gear (see Figures 7–9) with a nominal resistance of about 2000 kN (while having the same low price) in the structures of console-damping buntons, ensures the safe operation of the lifting installation at design parameters in the event of an emergency, even in case of broken one rope inside the guide and a series of blows.

In general, the developed structures of damper bunton using various types of dampers: shock absorbers (see Figure 3); shock absorbers with pneumatic cylinders (see Figure 4); draft gears (see Figure 7-9), which have high reliability and corrosion resistance, can significantly reduce the level of dynamic loads in two directions (when the vehicle hits the bunton and when it moves away from the shell, which can significantly reduce the shock wave damping time), arising in the "vehicle-RPG" system during emergency modes of movement of lifting vehicles and during the transition from one step to another. All these measures can significantly increase the safety and durability of the RPG and the entire skip hoisting unit as a whole, as well as significantly improve the safety of transporting people and auxiliary goods along the shaft depth with cage lifts.

4. Conclusions

The development and implementation of damper bunton structures with various degree of dynamic load reduction make it possible to achieve the following results:

– to ensure high reliability of RPG operation;
– to increase the service life of shaft reinforcement;
– to reduce labor intensity of maintenance and operation, compared to rigid reinforcement;
– to reduce metal consumption compared to rigid reinforcement;
– to reduce the level of dynamic oscillations at the meeting point of vehicles in the middle part of the shaft in the frontal and lateral planes even under significant emergency horizontal loads;
– to increase reliability of the kinematic connection in the "vehicle–RPG" system due to the use of bunton legs with connecting inserts;
– to reduce safety gaps per side – 350 mm for skip hoists, and – 500 mm per side for cage hoists along the entire depth of the shaft as for flexible reinforcements;
– to install damping buntons with a high level of damping in the form of a safety belt in the shaft.

In general, the use of various structures of console-damping buntons with devices in the form of pneumatic cylinders, shock absorbers, and draft gears makes it possible to significantly increase the level of damping even in emergency and highly loaded operating modes, and achieve a high service life and reliability level of the shaft equipment and the entire lifting complex as a whole, [1-12].

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ДОСЛІДЖЕННЯ І РОЗРОБКА КОНСТРУКЦІЙ ВИСОКОНАВАНТАЖЕНИХ РОЗСТРІЛІВ ДЛЯ ЗНИЖЕННЯ ДИНАМІКИ У СИСТЕМІ «ПОСУДИНА - АРМУВАННЯ»

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Анотація. Досліджено горизонтальні навантаження, що виникають при русі транспортних засобів під дією дисипативних сил (кручення канатів, аеродинамічні сили, навантаження транспортного засобу ексцентриситетом у фронтальній та бічній площинах), що діють на канатно-профільні провідника (далі – КПП або провідник). Розроблено конструкції демпферних розстрілів, які зменшують вібрації за рахунок взаємодії напрямних з демпферними елементами розстрілів різної конструкції, які розташовані в місці зустрічі транспортних засобів і далі по валу. Крок граничних розстрілів у місці зустрічі транспортних засобів у середній частині ствола має мінімальне значення, потім крок ступінчасто збільшується і далі залишається постійним. Розроблено кінематичний зв'язок КПП і ростріл у вигляді ніжки пунтона і з'єднувальних вставок, які дозволяють напрямній переміщатися вгору-вниз і згинатися на безпечну величину у фронтальному і бічному напрямках; потім горизонтальне навантаження гаситься за допомогою розстрільних демпферів і конструкції розстрілу. Консольні розстріли, розташовані по глибині шахти з постійним кроком, оснащені демпферами, які складаються з гумових вставок з м'якими металевими пластинами, зібраними за допомогою болтових з'єднань на консольному розстрілу. У місці зустрічі транспортних засобів у середній частині шахти амортизатори консольного розстріла мають більш складну конструкцію і складаються з амортизаторів, вбудованих у коробчатий розстріл, стрижень якого вбудований у ніжку розстріла, що переміщується в напрямних і гасить навантаження. Демпфери розстріла складаються з амортизатора і вбудованого пневмоциліндра і мають більший амортизуючий ефект. Розробка різноманітних конструктивних рішень розстрілів з демпферами для різних перерізів валу і кінематичного зв'язку роботи розстріла з канатно-профільними провідниками дозволяє досягти:

– високу надійність при роботі КПП;
– збільшення терміну служби за рахунок значного зниження рівня динамічних впливів;
– знижена трудомісткість обслуговування та експлуатації в порівнянні з жорстким армуванням;
– зменшена витрата металу в порівнянні з жорсткою арматурою.

Ключові слова: шахтні вертикальні стовбури, канатно-профільні провідники, консольно-демпферні розстріли, пневмоциліндр, амортизатори, поглинаючі механізми, рамні ферми, горизонтальні зусилля в лобовому та бічному напрямках.

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