Analysis of the causes of accidents of the VIPO 32-01 hydraulic lift

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Abstract. With the development of technologies, the number of accidents related to construction machines in one way or another increases. The article deals with the analysis of the causes of accidents of the VIPO 32-01 auto-hydraulic lift. According to the results of engineering and technical expertise, the cause of the accident was a break in the connection of the two upper traction chains with anchor bolts fixed to the main section of the boom. During this break, there was a spontaneous movement of the third and fourth sections of the telescopic boom of the auto-hydraulic lift. The main reason for the lack of strength of anchor bolts of the upper traction chains according to the results of the research was the use of steel grades with insufficient strength characteristics in their manufacture. Material did not have sufficient load-bearing capacity in the cross sections of the eyes of anchor bolts intended for fastening chains, for the perception of the calculated forces in the traction chains.

Keywords: structures, accidents, hydraulic lift, anchor bolt, hoisting machine, breakdown.

1 Introduction
Accidents on construction sites [1-3] occur almost everywhere [4-5]. Therefore, it is very important to prevent and reduce the number of accidents in the future [6-8] to analyze their causes and get to the bottom of it [9-12]. With the development of technologies [13-15], the number of accidents related to construction machines in one way or another increases [16-18]. Researchers in different parts of the world conduct a thorough analysis of such cases [19-20], accompanied by the development of new security techniques [21-22]. Research and testing are constantly carried out to minimize the number of errors and accidents [23].

Auto-hydraulic lifts are a class of lifting machines, characterized by a variety of design forms with a tendency to reduce the material consumption while improving the lifting characteristics in the form of lifting height, load capacity, improved handling, increased safety of work with the use of new safety systems. Attempts to obtain improved lifting characteristics of auto-hydraulic lifts are often implemented by using unverified design solutions in combination with critical errors in the choice of materials, components and connections during their implementation.

This article discusses the causes of the accident of the VIPO 32-01 hydraulic lift, No. 12, manufactured in 2015 by the private enterprise "Machine-building company "Vitebsk lifts", Republic of Belarus, Vitebsk, with improved technical characteristics in the form of an increased load capacity of up to 300 kg with a lifting height of up to 32 m, equipped with a safe management and control system SBUK 310.20-20.51, including a wind speed sensor, an intercom, an azimuth sensor, a displacement sensor and a force sensor, produced by NPP Resonance LLC.
Technical characteristics of the auto-hydraulic lift: chassis type KAMAZ-43118, load capacity 300 K, reach 19.2 m, support contour $5.06 \times 5.6$ m, lifting height 32 m. The lift is designed to work with ambient temperatures from -20°C to +40°C. The service life established by the manufacturer is not less than 12 years. The design of the boom is four-section with an additional knee. The mechanism for extending the boom sections has a complex kinematic scheme. The second section of the boom is extended by means of a hydraulic cylinder, the third and fourth sections are driven by two circuits of traction chains. The accident occurred in the form of a spontaneous movement of the sections of the telescopic boom and resulted in injuries to the personnel who were in the cradle at that time.

2 Materials and methods

2.1 Post-accident survey results

Let’s analyze the data from the printout of the system parameters and safety management of the VIPO 32-01 automatic hydraulic lift. №12 on the day of the accident, received by a specialized organization. From the printout of the parameter recorder on 15.01.2020, it is clear that the accident occurred at 11:12 am with a loading rate of 71% (approximately the weight of people and equipment in the cradle was estimated by the safety system of the auto-hydraulic lift of 210 kg). The discreteness of the sensor readings according to the printout is 20 seconds. The failure occurred in the time interval 11:12:27 and 11:12:47 with a sharp decrease of height of lifting the nacelle with a 16.5 m to 7.2 m and boom lifts from 2.9 m to 1 m. This sharp change in the parameters can explain the rapid spontaneous slide of the third and fourth sections of the telescopic boom, associated with the breakage of the chain mechanism of the traction chains of aerial truck-mounted platform.

According to the results of a condition survey of the lift VIPO 32-01 after the accident are: checks of the drives of the lift showing the following: Hydraulic extension poles, raising and lowering the main boom section, the extensions of the second section of the boom, rotation of the fourth boom section, the orientation of the cradle are all in working condition. The turntable drive is in working condition. The chain drives of the third and fourth sections of the boom are in a faulty state. The sections were not extended when the corresponding buttons and levers of the control panel were activated. The condition of the hydraulic system of the lift can be assessed as operable, there is no oil leakage from the system, and the wear of the connecting hoses is within the limits of acceptable values. The overall condition of the metal structures of the auto-hydro lift can be assessed as operable. No cracks were found in the undercarriage frame, boom, or frame nodes of the turntable. Local and general deformations of metal structures of the frame of the undercarriage, outriggers, arrows do not exceed the maximum permissible values and do not have visually noticeable signs of destruction.

Figure 1. Extension of the second section of the telescopic boom of the car lift to assess the condition of the drives after an accident.
The condition of the hydraulic lift structures at the time of the post-accident survey is shown in a series of figures (figures 1-8).

**Figure 2.** General view of the car lift after the accident.

**Figure 3.** The third and fourth sections of the telescopic boom did not extend due to a faulty mechanism of the traction chains due to the breakage of two chains at the place of their anchoring.
Figure 4. Loss of the traction chain LH1066 from the intersectional space of the boom due to the weakening due to the breakage of its attachment to the anchor bolts to the main boom in the upper belt zone, which occurred when the second section of the boom was extended.

Figure 5. Undamaged anchorage nodes of 2 lower traction chains LH1066 to the main section of the boom in the zone of the lower belt. The photo shows that the possible wear of the holes of the anchor bolt eyes is not visible, closed by the links of the traction chain.
Figure 6. Damaged anchor devices of 2 upper traction chains LH1066 to the main section of the boom in the upper zone. Only the anchor bolts with the eyes torn off are visible. The severed ends of the chain fell into the intersecting space of the telescopic boom.

Figure 7. The broken eye of the anchor bolt of the traction chain LH1066, fixed to the main section of the boom in the upper belt zone.
Figure 8. The traction plate chain LH1066, the break in the fastening of which caused an accident of the lift in the form of spontaneous movement of the third and fourth sections of the auto-hydraulic lift during its operation.

2.2 Estimation of reasons for traction chain breakage

To assess the reasons for the breakage of two traction chains in the places where they are anchored to the anchor bolts to the main (first) section of the telescopic boom of the VIPO-32-01 car lift, the following elements of the mechanism of the traction chains of the car lift were removed to clarify the strength and geometric characteristics (figures 9-14):

1. Two ragged in places of anchoring top traction chains (figure 9).
2. Anchor bolts for attaching traction chains to the main section of the boom that were damaged during breakage (figure 11) – 2 pieces.
3. Anchor bolt for fastening the lower traction chains, which has no signs of destruction, taken for comparison (figure 14) – 1 piece.

Fragments were removed from one of the two chains for chemical analysis of steel and testing of the chain fragment for breaking. One of the bolts was also sent for chemical analysis of the steel. Studies of the chemical composition of steel samples were performed in the laboratory of the NC and ROK service of metals and welding LLC. Tests of the sample-fragment of the chain for breaking were performed in another laboratory.

Figure 9. Traction chains of the VIPO-32-01 auto-hydraulic lift, the breakage of their attachment to the anchor bolts led to an accident of the lift.
Figure 10. The end of the traction chain connected to the eye of the anchor bolt. It can be seen that there is no damage to the chain assembly that was inserted into the eye of the anchor bolt. The end roller of the chain with wire pins can be seen, inserted when connecting to the anchor bolt in the holes of the anchor bolt eye.

Figure 11. Anchor bolts for attaching the upper traction chains to the main section of the boom.

Figure 12. Anchor bolt for attaching the upper traction chain to the main section of the boom. At the end of the bolt, there are eyelets (end plates) and a stop (middle plate) for connecting to the traction chain.
Figure 13. Measurement of geometric parameters of the broken anchor bolt eye at the explosion site. It can be seen that the middle plate is not made in the form of an eye, but in the form of a stop for the extreme roller of the traction chain, which significantly reduced the strength of the anchor bolt on the cut in the cross section of its eyes.

Figure 14. Anchor bolt, taken for comparison, of the lower traction chains, without damage. The difference from broken anchor bolts is that the middle element of the bolt zone with eyelets is made as an eye, and not as a stop, i.e. the bearing capacity of such a bolt on the cut in the section of the eyes is 1/3 higher than that of anchor bolts that received a break in the eyes.

The complex kinematic scheme of the auto-hydraulic lift, the lack of actual design parameters of the circuit elements did not allow us to establish the exact value of the maximum calculated tensile force in the traction chain LH1066, which occurs when the auto-hydraulic lift is operating. Therefore, as a parameter of the possible maximum calculated tensile load in the chain LH1066, the value of the calculated force given in paragraph 3.5 "characteristics of the chains" of the passport of the auto-hydraulic lift, equal to 19 kN, was adopted.

We evaluate the bearing capacity of the M24 anchor bolt that receives the tensile forces from the traction chain.

The bearing capacity of the cross section of the bolt can be estimated by Eq. (1) from SP 16.133330.2017 "Steel structures":

$$N_b = R_{bt} \times A_{bn} = 2250 \times 3.53 = 7942 \text{ kg} = 79.42 \text{ kN} \geq 19 \text{ kN},$$

where $R_{bt}$ – calculated tensile strength of the bolt;

For St.20 $R_{bt} = 2250$ kg/cm$^2$ as for strength class 5.6 according to the table. G. 5 of SP 16.133330.2017 "Steel structures".

$A_{bn}$ – the cross-sectional area of bolt net, $A_{bn} = 3.53$ cm$^2$ according to the table. G. 9 of SP 16.133330.2017 "Steel structures".

Conclusion: the cross section of the anchor bolt with a diameter of 24 mm made of ST20 steel is sufficient for the perception of the calculated force of the traction chains.

We perform a test calculation of the cross section of the eye of the anchor bolt of the traction chain LH1066, in order to determine the value of the cross-section of the eyes of the stretching forces in the traction chain.

We determine the maximum calculated value of the load from the traction chain that does not cut off the anchor bolt eyelets using the Eq. (2):

\[ N = R_s \times n \times t \times L_{ey} \]  

where \( R_s \) – calculated cross-section shear resistance of the bolt material, \( n \) – number of eyes, \( n = 2 \), \( t \) – the thickness of the cross-section of an eye, \( t = 4 \) mm, \( L_{ey} \) – the size of the eye section from the edge of the eye hole to the edge of the eye in the direction of the axis of the traction chain.

\[ R_s = 0.58 \times R_y = 0.58 \times 2450 = 1421 \text{ kg/cm}^2 \]  

(3)

We estimate the value of the breaking force of the eyelets of the anchor bolts of the traction chain at the moment of their rupture, which have a residual cross section of each eye -4 × 0.35 mm.

\[ N = R_s \times n \times t \times L_{ey} = 1421 \times 2 \times 0.4 \times 0.35 = 397 \text{ kg} = 3.97 \text{ kN} \]  

(4)

We estimate the value of the breaking force of the eyelets of the anchor bolts of the traction chain, which have a design section of each eye that is not weakened by plastic deformations -0.55 × 4 mm.

\[ N = R_s \times n \times t \times L_{ey} = 1421 \times 2 \times 0.55 \times 0.4 = 625 \text{ kg} = 6.25 \text{ kN} \]  

(5)

We estimate the bearing capacity of the anchor bolt shown in figure 14 and having three eyelets for attaching the traction chain, in the calculated cross-section of the eyelets:

\[ N = R_s \times n \times t \times L_{ey} = 1421 \times 3 \times 0.55 \times 0.4 = 937 \text{ kg} = 9.37 \text{ kN} \]  

(6)

**Conclusion:** These calculated permissible forces, perceived by the cross section of the anchor bolt in the area of its eyes, are still significantly less than the calculated force in the chain, given in the passport of the hydraulic lift and equal to 19 kN.

We define the desired value of the calculated resistance on the shear of the anchor bolt design section of the eyes for the perception of design efforts in the traction chain equal to 19 kN.

\[ R_s \geq \frac{N}{(n \times t \times L_{ey})} = 1900(2 \times 0.6 \times 0.4) = 3958 \text{ kg/cm}^2 \]  

(7)

High-strength bolts of class 10.9, made of steel with a calculated yield strength, have this calculated shear resistance \( R_s = 9000 \text{ kg/cm}^2 \).

**Conclusion:** when manufacturing anchor bolts with a strength class of 10.9, the bearing capacity of the bolts in the eye area with a calculated force of 19 kN would be reduced.

3 Results and discussion

The studies of the obtained samples of chains and anchor bolts showed the following:

1) According to their geometric parameters and strength characteristics, the provided traction chains fully comply with the marking LH1066 DIN 8152, given in the passport of the hydraulic lift for these traction chains. The main actual characteristics of the chain: a plate chain, with a 15.88 mm shaft, of 6 links, the chain length is not less than 6.8 m. a breaking force of 114.8 kN was obtained during testing of the chain fragment, which corresponds to the minimum equal force of 100 kN given in the chain standard. The steel of the traction chain elements corresponds to high-strength, wear-resistant 45G steel with a high surface hardness of at least HB 400.

2) Anchor bolts for fastening traction chains have the following parameters: length 155 mm, M24. The bolts have a design feature at the end of the bolts made 2 lugs with holes for roller chain (end plates) and the emphasis for fixing extreme roller chain (figures 11 and 13). The steel of anchor bolts according to the results of chemical analysis corresponds to steel 20 with a low surface hardness NV190.

3) There is a discrepancy between the parameters of the characteristics of the traction chains LH1066, given in paragraph 3.5 of the passport of the hydraulic lift in the following points:

- the actual length of the chain was at least 6800 mm against the value specified in the passport that is at least 7800 mm;
the breaking force of the chain LH1066 according to DIN 8152 is not less than 100 kN, according to the results of tests for breaking 114.8 kN against the value of 122 kN specified in the passport.

4) The provided samples of LH1066 traction chains do not have visually noticeable signs of damage and wear both along their entire length and in the end nodes – in the nodes of their anchoring in the eyes of anchor bolts.

5) There is no information about the material of anchor bolts of traction chains in the passport and in the manual of the hydraulic lift.

6) Anchor bolts taken at the breakage points of the LH1066 traction chain anchorage have traces of a break in the cross sections of the bolt eyes (figures 12-13) with traces of plastic deformations of the eyelet holes, as evidenced by the oval shape of the eyelet holes, which significantly exceeds the diameter of the extreme rollers of the traction chain (6 mm) and the deformation of the edges of the torn eyelets. The residual cross section of each of the two bolt eyes at the moment of their rupture can be estimated by measuring the size of 3.5×4 mm. The dimensions of the oval holes of the eyelets at the moment of rupture can be estimated by the measurement results in sizes up to 8.5×6.5 mm with the design size of the hole equal to the diameter of the chain roller 6 mm. These parameters of damaged eyes anchor bolts show that the rupture of the lug bolts did not occur simultaneously, but with the accumulation of plastic deformations in the process of operation of auto-hydraulic lift in the form of increasing the size of the hole of eyes and reduction of the residual thickness eyes before the onset of the case when tensile forces in the traction circuits of the third and fourth sections of auto-hydraulic lift exceeded the carrying capacity of the walls of the eyelets of anchor bolts shear. Such a failure mechanism became possible with a small period of operation of the hydraulic lift (5 years with a standard service life of 12 years established by the manufacturer) due to the discrepancy between the material of anchor bolts and the calculated forces perceived by the traction chains.

7) Comparison of upper traction chain anchor bolts (figure 11), which received a break in the eyelets with the anchor bolt of the lower traction chains, without damage (figure 14), revealed a structural feature of the damaged anchor bolts, consisting in the fact that the damaged anchor bolts fastening the extreme roller of the traction chain is carried out to the extreme eyes, and the middle plate "eyes" part of the bolts were the focus and had no signs of rupture, and intact specimen anchor bolt, in all three plates “eyes” part had holes for mounting. This design difference reduced the load-bearing capacity of the eyelets of damaged bolts with 2 eyelets for attaching the chain by 1/3, compared to an undamaged sample of an anchor bolt with 3 eyelets for attaching the chain.

4 Conclusions
Based on the test calculations of the bearing capacity of the anchor bolts of the traction chains LH1066 of the VIPO 32-01 auto-hydraulic lift, the following conclusions can be drawn:

1) Accepted as the material of anchor bolts "soft" plastic steel corresponding to the brand St20 (according to the results of chemical analysis) does not have sufficient load-bearing capacity in the cross sections of the eyes of anchor bolts intended for fastening chains, for the perception of the calculated forces in the traction chains, the values of which are specified in the passport of the hydraulic lift.

2) To ensure the required load-bearing capacity of anchor bolts with their geometric parameters of eye holes for fixing traction chains, the use of high-strength anchor bolts of class 10.9 or more was required to perceive the calculated force in chains of 19 kN.

The nature of the damage of anchor bolts pulling chains shows that the gap eyelets anchor bolts did not occur simultaneously, but with the accumulation of plastic deformations in the process of operation of aerial truck-mounted platform in the form of increasing the size of the hole of eyes and reduction of the residual thickness eyes to the critical value at which the ruptured eye bolts. The accumulation of plastic deformations was expressed in the increase of holes in the eyelets in diameter and the formation of oval shaped holes with the maximum size of an ellipse oval holes up to 8.5 mm instead of round ones with a diameter of 6 mm for the diameter of the extreme rollers of traction chains.
The detection of such wear of eyelet holes during operation of the car lift should be considered difficult due to the following factors:

1) The holes of the anchor bolt eyelets are quite tightly covered from visual inspection by the extreme plates of the chain links.

2) There are no criteria for the maximum permissible parameters of these damages and specific recommendations about the need to control these structural elements in the operating manuals and in the passport of the hydraulic lift.

3) A factor weakening the traction chain with a length of 6.8 m due to wear of the holes in the lugs 3 mm as an indirect criterion, indicating the need to control the attachment of the traction chains is not significant due to the presence of many other more likely factors of attenuation, for example from freezing rollers and sections of chain debris in the intersection space and the insignificance of slack chain with its “elongation” of 3 mm.

Conclusion: Based on the above, we can draw a conclusion about the confident detection of such damages to anchor bolts as wear of the holes of their eyes only when analyzing the connections of anchor bolts with traction chains.

According to the results of research carried out to identify the causes of accidents of the hydraulic lift, the following conclusions were made:

1) According to the results of engineering and technical expertise to identify the causes of accidents, the cause of the accident of the VIPO 32-01 № 12, which was released on 15.01.2020, was a break in the connection of the two upper traction chains LH1066 with anchor bolts fixed to the main section of the boom. During this break, there was a spontaneous movement of the third and fourth sections of the telescopic boom of the auto-hydraulic lift. The cause of the rupture of unity of anchor bolts attaching the upper conveyor chains was sufficient probability of the structural strength of the installed anchor bolts in cross sections of existing bolts in the eyelets made for mounting to the anchor bolts rollers (axles) traction chains. The break in the cross sections of the anchor bolts of the upper traction chains LH1066 occurred at operating loads that do not exceed the rated values.

2) The main reason for the lack of strength of anchor bolts of the upper traction chains according to the results of the research is the use of steel grades with insufficient strength characteristics in their manufacture: the calculated resistance of the material to the cut, the hardness to exclude plastic deformations in the bolt eyes. The research found that the material of anchor bolts that broke in the area of their eyes, according to their characteristics corresponds to the brand of structural steel St 20, while the values of the calculated forces in the traction chains specified in the crane passport required the use of high-strength bolts with a strength class of at least 10.9.

3) The conclusion about the insufficient strength of the material used in addition to anchor bolts made in the examination of research is supported by the following indirect signs: significant plastic deformation of metal eyelets of anchor bolts pulling chains when they break, no load at break of the eyelets of anchor bolts (in the time of the accident) on the design of lifts exceeding the certified value.

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