Mobile trailer support arm: modeling and analysis of breakage

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Abstract. Calculation of vehicle elements load is a mandatory operation in the engineering of transport. The paper presents the calculation schemes of the static loading of the lever supports of the mobile hopper of bulk materials and determines internal force factors. The numerical values of equivalent stresses distributed on the lever of the mobile hopper of bulk materials are determined. The visualization of the results of calculating the stresses performed by the classical cross-section method and the finite element method is given. The results of both calculations show that the dangerous zone in the cross section of the lever is the neighbourhood of the hydraulic cylinder attachment. The analysis by the loading method shows the risk of breakage in the place of attachment of the hydraulic cylinder bracket from the side of the support wheel. To eliminate the revealed shortage there are proposals and recommendations given by the authors.

1. Introduction

Ensuring the required quality of product indicators is an urgent task of machine building and instrument making industry. Quality is a complex indicator, in the composition of which one can single out the working efficiency of machine-building product determined mainly by the main criteria as strength. Strength is laid at the design stage of the product. To do this the product is calculated for strength under static and dynamic loads at the checking calculation stage [1, 2]. An additional condition of operability is to ensure the rigidity of the structure [3, 4].

At present, strength calculation is widely provided by Computer Aided Design systems (CAD) [5, 6] assigning 3D models of the final product, external force factors (location of application, nature of the load, their numerical value or law of variation) and the boundary conditions. After setting necessary CAD system parameters the specific calculations are performed by finite element methods giving visualization of a particular product with calculated strength values and estimated strength conditions [6].
However, despite the widespread use of strength calculations in CAD systems, classical methods for calculating strength and rigidity based on material resistance methods and elasticity theory may be more relevant [1-3].

Although numerical analysis [7] of the reasons causing the breakage of trailer support levers near the attachment of the hydraulic cylinder has been made, there is still a wide variety of structures of support arms used in machines and devices, and problems inducing mechanism failure at material exploitation.

The aim of the work was to reveal the most loaded sections of the support bracket of the mobile wheel trailer and the main possible places for its breakdown.

2. Theoretical research

We investigated the internal force factors arising in the support lever of the discrete materials bunker of the transport trailer. The loading and attachment conditions of the support lever under static conditions were justified in [7]. In this paper, the variation of stress along the length of the support lever by theoretical methods was studied. To calculate the distribution of equivalent stresses along the axis of the lever, we used the cross-section method. The working capacity of the support lever was tested according to the strength condition. The search for the zone of increased stress values of the lever was carried out under static loading. The maximum value of stresses did not exceed the allowed stresses taking into account the availability of the safety factor for multiple shock load. The calculation scheme for placing the support lever, for determining the external nature of loading, had the form shown in Figure 1.

![Figure 1](image)

**Figure 1.** Scheme of the support lever static loading: 1 – bunker; 2 – frame; 3 – support arm; 4 – support wheel; 5 – basic hinge; 6 – hydraulic cylinder lifting the frame with a bunker; A – joint hinge of the trailer to the mover; B – joint hinge of the support lever to the frame of the trailer; C – the center of gravity of the frame with the trailer bunker; D – wheel axle; E – the joint hinge of the hydraulic cylinder to the support arm; F – the joint hinge of the hydraulic cylinder to the frame leg of the trailer.

For the presented design scheme, external force factors were determined that acted on the support lever under static loading with equation (1) determining the value of the load (N) required to define the reactions of lever supports for mobile bunker of loose materials:
where \( P \) – vertical projection of the force action of the trailer's weight to the point of attachment of the hydraulic cylinder to the support lever, \( N; a, b, c \) and \( e \) – distances between constructive elements (Figure 2), \( m \).

The design diagram of the support arm 3 (Figure 1) as a figure of B, E, and D points lever in space, as shown in [7], can be represented in the form shown in Figure 2 used to obtain the dependencies between forces and moments.

\[
N = \frac{P \cdot (a + b - e - c)}{2 \cdot (a + b)}, \quad (1)
\]

moments bending along the Z and Y axes about the B axis were found as:

\[
M_{Bz} = N \cdot \cos(\alpha) \cdot l_{4x} \quad \text{and} \quad M_{By} = N \cdot \sin(\alpha) \cdot l_{4x}. \quad (3)
\]

Figure 2. Calculation diagram of the support arm 3 of the mobile trailer (Figure 1): B – cylindrical hinge for mounting to the frame 2, E – spherical joint for hydraulic cylinder mounting, D – wheel support, N, NE, active force YB, ZB– reaction of the arm mount support, MBZ, MBY – moments bending along the Z and Y, \( \alpha \) – angle between longitudinal axis of the cylinder and the normal to the lever, \( l_{1z}, l_{2z}, l_{3y}, l_{4x} \) – projection lengths of the lever on the respective axes.

According to Figure 2 the forces at the points of linking the lever with other elements of the structure (the reaction of external and internal bonds) shown in Figure 1 were determined. We calculated the force of hydrocylinder rod action on a support lever as follows:

\[
N_E = \frac{N \cdot \cos(\alpha) \cdot (l_{1z} + l_{2z})}{\cos(\alpha) \cdot l_{1z} + \sin(\alpha) \cdot l_{3y}}, \quad (2)
\]

Further, we calculated the reaction of the supports along the axes at point B (Figure 1):

\[
Y_B = N_E \cos(\alpha) - N \cos(\alpha) \quad \text{and} \quad Z_B = -N_E \sin(\alpha) + N \sin(\alpha), \quad (4)
\]

where \( \alpha \) – angle between the longitudinal axis of the hydraulic cylinder and the normal to the lever, radian; \( N \) – balancing force of the wheel on the support arm, \( N; l_{1z}, l_{2z}, l_{3y}, l_{4x} \) were the lengths of the structural element (Figure 2).

We used the obtained values of external force factors to determine internal force factors (longitudinal forces, transverse forces of the corresponding projections of the lever sections, bending forces, etc.).
moment, and torque in the corresponding hinges) arising at the corresponding points of the lever sections.

The longitudinal forces along the z axis for point D and E are defined as:

\[ N_{zD} = -N \cdot \sin(\alpha); \]  
\[ N_{zE} = -N \cdot \sin(\alpha) + N_E \cdot \sin(\alpha); \]  
\[ N_{zE} = -N \cdot \cos(\alpha) + N_E \cdot \cos(\alpha). \]  

The transverse forces along the x and y axes are defined as:

\[ Q_{xD} = N \cdot \cos(\alpha); \]  
\[ Q_{yD} = -N \cdot \cos(\alpha); \]  
\[ Q_{yE} = -N \cdot \cos(\alpha) + N_E \cdot \cos(\alpha). \]  

The bending moments along the x and y axes are defined as:

\[ M_{yD} = M_{By}; \]  
\[ M_{xB} = 0, \]  
\[ M_{xE} = Y_B \cdot l_z, \]  
\[ M_{xD} = Y_B \cdot (l_{1z} + l_{2z}) - N_E \cdot \cos(\alpha) \cdot l_{2z} + N_E \cdot \sin(\alpha) \cdot l_{3y}; \]  
\[ M_z = M_{Bz}. \]

Analysis of the design scheme and expression for internal force factors allowed us to conclude that the lever had a complex form of loading - tension and twist with torsion.

In this case, the strength condition of the product was determined by the third or fourth strength theories for the principal stresses:

\[ \sigma = \frac{N}{A} + \frac{M_{\Sigma}}{W} \leq [\sigma], \]  
\[ W_y = \frac{h \cdot b^2}{6} - \frac{h_1 \cdot b_1^2}{6}, \]  
\[ W_x = \frac{b \cdot h^2}{6} - \frac{b_1 \cdot h_1^2}{6}, \]  
\[ M_{\Sigma} = \sqrt{M_{\sigma}^2 + M_{\tau}^2}, \]  
\[ M_{\Sigma} = \sqrt{M_{\sigma}^2 + 0.75 \cdot M_{\tau}^2}, \]  
\[ \sigma = \frac{N}{A} + \frac{M_{\Sigma}}{W} \leq [\sigma]. \]

3. Results and discussion

The analysis of equivalent stress diagram (Figure 3) showed that the largest value of equivalent stresses (about \(1.304 \times 10^8 \text{ Pa}\)) was located near the point E (Figure 2). Therefore, the most
dangerous cross-section of the lever was the cross section in the neighbourhood of the hydraulic cylinder mounting. As the coordinates of the lever approached the support point B (Figure 2), the stresses slightly decreased. When the lever coordinates approached the support point D (Figure 2), the magnitude of the stresses dropped sharply and substantially.

![Figure 3](image-url)  

Figure 3. Diagram of the distribution of equivalent stresses along the axis of the lever.

Equivalent stress distribution diagram $\sigma$ (Sigma, PA) of lever 2 (Figure 2) along its axis for points at a distance $z=[0, l_1+l_2]$ (m) from point B. The obtained results were confirmed by the calculation of the lever by finite element method (Figure 4): the hinge mount of the lever to the frame (point B, Figure 1) was the main support of its attachment. With respect to the joint in the given point, the lever was deformed. Considering the hinge mount in points B and E (Figure 1), the fit in these hinges was made with a gap. In addition to the nominal design gap size, there was an actual clearance due to tolerance size and the normal size distribution law in the process of manufacturing the parts.

Thus, the presence of gaps in the conjugation leads to the possibility of a lever rotation in point B around z axis. As a result of combination of possible turns of the lever elements at these B and D points, two ways are possible as to include or exclude a reserve of possible rotation of the hinge around the z-axis in point E. The results of modeling for both variants of joining the lever using the finite element method performed in the CAD system are presented below.

Figure 4 shows the results of calculating the stresses distributed over the lever in accordance with the indicated options. When moving from B to E point (Figure 4a), the color turned from blue into green that confirmed the stresses growth and the greatest stresses was near the upper brace (for E point) of the cylindrical support in point D. There appeared a small area of the surface with a shade of yellowness (Figure 4a). The transition of color from green to yellow or further to red, indicates an increase in The results obtained corresponded to analytical calculations. The largest stresses are located near point E in Figure 2.

In the second version of the calculations, when moving away from point B, the stress value also went up (color changed from blue to green on Figure 4b), but in E point it faded. The cylindrical hinge in point E assumed a load from the twisting of the lever. Near point E, at the upper brace there was also a platform on the side face with increased stresses (green color). The specified place of increased stresses for the two loading options worked for scrapping due to the oscillations in the lever during its operation.
In addition, the twisting of the lever resulted in the transfer of the load from the pair of brackets of the hinge (point E) to the near bracket, that further caused the stress in the stress concentration zone (Figure 1).

The bend of the hinge axis in point E could also affect the duration of the normal operation of the hydraulic cylinder due to the bending of the rod. When the trailer moved depending on the magnitude of the applied load (the presence of fluctuations in the magnitude of the applied force in point D), the alternating operation of the lever in both loading modes was possible (Figure 4).

**Figure 4.** Distribution of stresses along the arm for attaching (a) and joining (b) the lever to point B on cylindrical faces with force applied at an angle $\alpha$ at point D and connector at point E of spherical bearing.

**Conclusion**

In the paper the calculation of the support lever of a transport trailer was made. Then the analysis of possible impacts of supporting wheels on the supporting arm made it possible to establish the causes and the place of support levers breakdown during vehicles exploitation, and, further, to give to recommendations for breakdowns elimination.

It has been shown that regardless of calculation method, there is a dangerous zone in the cross section of the lever in the vicinity of the joint of the hydraulic cylinder. Analysis of loading methods and unavoidable load fluctuations in the high stress zone has demonstrated the danger of breakage in
the place of hydraulic cylinder bracket joint from the side of the support wheel, which was confirmed by breakdowns in some vehicles.

To eliminate the revealed shortage, it is necessary to avoid the appearance of bending moments (analogs to $M_{Bz}$ and $M_{By}$) in the axis of fastening of the hydraulic cylinder. To do this, we propose to use the spherical support of the hydraulic cylinder or increase the clearance in the hinge at the outer bracket. Alternative but not the best way may include the increase of the lever rigidity.

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