Calculation and comparative analysis of bucket of the belt elevator

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Abstract. The calculations of the bucket of a belt elevator for two working cases are presented - at the moment of scooping up the load by the bucket and at the moment of transporting the load into the vertical direction. A 3D model of the bucket was developed in the SolidWorks software package. The calculations of strength and stiffness of the bucket were performed. A comparative analysis of one size range of a bucket with different thicknesses of its walls is carried out.

1. Introduction

Currently, there is a continuous improvement and development of engineering directions, involving the robotic industry [1], various transport systems [2-4], including friction and wear in the nodes of conveyor transport [5, 6].

Continuous transport machines are one of the main means for the bulk cargo transportation in various industries. During the operations at mining enterprises, different kinds of this type of transport could be involved into the conjunction with the construction and road machines that perform various operations for handling, sorting and ragging the transported cargo.

In the process of the vertical handling of bulk cargo, it is advisable to use bucket elevators [7-9] of various types (belt and chain), with the metal buckets as working (carrying) bodies (figure 1). Depending on the pitch of their attachment to the traction elements (for belt elevators - a conveyor belt, for chain elevators - a chain or a pair of chains) and the height of the elevator itself, which on average reaches 40 meters [7-9], the number of buckets would differ.

![Figure 1. Design sketch of a deep type metal bucket [4].](image-url)
Therefore, it is advisable to carry out the optimal design of the metal structure of the elevator [10-15], which consists in reducing the mass of the bucket while meeting the conditions of strength and rigidity of its structure, as since it is an urgent task at the design stage of this machine. Achievement of the set task would lead to the decrease in the load acting on the metal structure of the elevator and, as a consequence, to the decrease in its stress-strain state.

2. Design model

A deep type G bucket (figure 1) with the following characteristics was chosen as the load-carrying element of the belt elevator: width \( B = 500 \text{ mm} \); overhang \( L = 235 \text{ mm} \); height \( H = 255 \text{ mm} \); radius \( R = 75 \text{ mm} \); wall thickness \( t = 4 \text{ mm} \); material - carbon sheet steel; capacity - 12 litres. The transported cargo is oats with a density of \( 0.6 \text{ t} \cdot \text{m}^{-3} \).

During the operation of the belt elevator, at first the buckets scoop up the load, after that - they move it into the vertical direction. It follows from the above, that the design of bucket of the belt elevator must be carried out for two working cases.

When the bucket scoops up the load, specific resistance arises, acting evenly on the leading edge of the bucket

\[
W_{sc} = K_{sc} \cdot q_l
\]  

(1)

\( K_{sc} \) – load coefficient; \( q_l \) – distributed load from the mass of the cargo.

In the process of vertical movement of the load, the pressure of the load is carried out on the bottom \( P_{\text{bottom}} [16, 18] \), side vertical walls \( P_{\text{side}} \) and on the inclined walls of the bucket \( P_{\text{iw}} \).

\[
P_{\text{bottom}} = \frac{m_c \cdot g}{A_{\text{bottom}}},
\]  

(2)

\( m_c \) - weight of cargo in the bucket; \( g \) – gravitational acceleration; \( A_{\text{bottom}} \) – bucket bottom area.

Pressure on the side vertical walls of the bucket \( P_{\text{side}} [17-19] \)

\[
P_{\text{side}} = k \cdot P_{\text{bottom}}
\]  

(3)

\( k \) – lateral ratio.

Pressure on the bucket inclined walls [17-19]

\[
P_{\text{iw}} = \left[1 - (1 - k) \cdot \sin \beta\right] \cdot P_{\text{bottom}},
\]  

(4)

\( \beta \) – bucket sidewall angle.

Bucket gravity:

\[
F_{\text{buck}} = m_{\text{buck}} \cdot g,
\]  

(5)

\( m_{\text{buck}} \) – bucket weight.

After sequentially performing calculations on the dependences (1) - (5), the following results were obtained for further research: \( W_{sc} = 137 \text{ N} \), \( P_{\text{bottom}} = 858 \text{ N} \); \( P_{\text{side}} = 378 \text{ N} \); \( P_{\text{iw}} = 545 \text{ N} \); \( F_{\text{buck}} = 95 \text{ N} \).

A 3D model of a belt elevator bucket was created in the SolidWorks software package (figure 2). Later, it was transformed into a finite element model (figure 3).
Figure 2. 3D-model of the belt elevator bucket.  

Figure 3. Finite element model of a belt elevator bucket.

On the basis of the obtained model, the design scheme of the bucket was formed for each of the two working cases. The number of rigid restrictions were set (places of attachment of the bucket to the belt) and loads (the gravity of the bucket and the external effect on the bucket from the load side) (figures 4, 5).

Figure 4. Design scheme for scooping up the load with a bucket: 1 - hard constraint; 2 - external impact on the leading edge of the bucket.

Figure 5. Calculation diagram of the vertical movement of the load by the bucket: 1 - the gravity of the bucket; 2 – hard constraint; 3 - pressure on the bottom and walls of the bucket.

For two working cases, the strength and stiffness calculations of the bucket were carried out. The results of stresses and strains are shown in figures 6, 7.

Figure 6. Result of calculating the bucket during scooping up the load: a - stress distribution; b - strain distribution.
Figure 7. Result of calculating the bucket during the vertical movement of the load: a - stress distribution; b - strain distribution

The calculations were done for a bucket with a wall thickness of 4 mm.

3. Results and discussion

As it could be seen from the results of the calculation of the bucket, the maximum stresses during the scooping up the load occur at the points of the bolted connection of the bucket with the conveyor belt. They are equal to 37.8 MPa. The maximum stresses during the vertical movement of the load also arise at the points of the bolted connection of the bucket with the conveyor belt. They are equal to 18.3 MPa.

By analogy, the structures of the bucket with wall thicknesses of 3 and 2 mm were calculated. The results of the stress-strain state are represented in table 1.

Table 1. Results of the stress-strain state of the bucket.

| №  | Wall thickness (mm) | Stress (MPa) | Deflections (mm) | Bucket weight (kg) |
|----|---------------------|--------------|------------------|--------------------|
|    | during scooping up the load with a bucket | during the vertical movement of the load | during scooping up the load with a bucket | during the vertical movement of the load |
| 1  | 4                   | 18.3         | 33.8             | 0.3                | 0.5                | 9.8 |
| 2  | 3                   | 19.8         | 39.1             | 0.5                | 1.1                | 7.3 |
| 3  | 2                   | 42.1         | 94.8             | 1.1                | 2.4                | 4.9 |

Comparative analysis of the results obtained for buckets (based on table 1):

1. The mass of a bucket with a wall thickness of 2 mm is 2 times less than the mass of a bucket with a wall thickness of 4 mm.

2. Maximum stresses in a bucket with a wall thickness of 4 mm, during scooping up a load, are 2.3 times less than the maximum stresses in a ladle with a wall thickness of 2 mm.

3. The maximum deflection occurs in a bucket with a wall thickness of 2 mm and is equal to 2.4 mm, which is 4.8 times higher than the maximum deflection in a bucket with a wall thickness of 4 mm.

4. Stresses and deflections of the bucket when moving the load in the vertical direction are greater than during scooping up the load with a bucket.

4. Conclusions

The below conclusions could be done, based on the results of the represented work:
1. Design diagrams were formed and calculation of two working cases of a belt elevator bucket was carried out. The obtained results stress-strain states do not exceed the maximum values.

2. A comparative analysis of the results of buckets with different wall thicknesses was done. For oats transportation with a belt bucket elevator, buckets with a smaller wall thickness than the minimum standard thickness of 4 mm are acceptable. The minimum permissible wall thickness for these conditions could be taken as a thickness of 2 mm. It is impractical to take less, as since the rapid abrasion of the bottom and walls of the bucket with a wall thickness of less than 2 mm on the transported load is possible during the operating process.

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