Improving the efficiency of gravity devices for grain transport

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Abstract. The article is devoted to the current problem of improving the efficiency of mechanized grain processing by reducing its mechanical damage during the operation of gravity transporting devices. It was found that as a result of high-speed movement of grain material with a low flow density, the number of impacts of grains on each other and on the walls of the gravity device increases, which increases the probability of damage to individual grains. To reduce the speed of the grain flow, a variant of a portioned grain pipeline with gravity-driven flaps is proposed. Calculations and experimental studies show that the speed of grain flow can be reduced to 2.5 m/s, which significantly reduces the damaging ability of the gravity device with constant performance.

1. Introduction

During mechanized processing of grain batches, as a result of interaction with the working bodies of machines, individual grains of agricultural crops are injured, that is, they are mechanically damaged. The number of such damaged grains in the batch (hereinafter—mechanical damage) according to the data [1–5] reaches a value that significantly exceeds the limits defined by the standards for the quality of grain material. In particular, this situation occurs in the operation of gravity devices that are part of grain cleaning complexes. This is due to the fact that at a low density of grain flow and high speed of movement, the number of impacts of grains on each other and on the walls of the gravity device increases, which increases the probability of damage to the grain during its transportation. The effect of this impact interaction is aggravated by the presence of heavy abrasive particles in the grain pile that have a greater hardness than the grain. In addition, as a result of self-separation, abrasive particles are deposited and when moving along the bottom of the grain pipeline accelerate its wear.

Since it is impossible to completely exclude damage to grain during mechanized processing, the search for ways to reduce the amount of mechanical damage by improving the technical means and technological scheme of its processing is relevant and has large economic significance.

2. Problem statement

The damage to grain by gravity devices is affected by its humidity, the number of passes through the machine [6] as well as the speed of grain movement along the grain pipeline $v_{\text{max}}$. Excluding the influence of the first two parameters and determining the damage capacity of machines $\beta$ according to the method [7], we note that the value of this indicator largely depends on the height difference $H$ and the angle of inclination of the grain pipeline $\alpha$ (Table 1).
Table 1. Damage capacity of grain pipelines $\beta$ depending on their design and operating parameters

| $H$, m | $\alpha$, degrees | $Q$, kg/s | $v_{max}$, m/s | $\beta$ |
|--------|-------------------|-----------|----------------|--------|
| 2.60   | 46                | 3.25      | 4.3            | 0.33   |
| 3.60   | 59                | 3.25      | 5.2            | 0.76   |
| 2.70   | 46                | 1.08      | 4.3            | 0.50   |
| 3.00   | 42                | 0.78      | 4.4            | 0.32   |
| 3.10   | 46                | 0.44      | 4.3            | 0.46   |
| 3.84   | 59                | 1.13      | 5.6            | 0.77   |

The damaging capacity of gravity devices also depends on the value of the filling coefficient of the cross-section of the grain pipeline $\psi$, determined by the expression

$$\psi = \frac{4Q}{S\gamma v}$$  

(1)

where $S$ is the cross-sectional area of the grain pipeline, m$^2$; $\gamma$ is the volume mass of grain, kg/m$^3$; $v$ is speed of grain movement in the grain pipeline, m/s. For the values shown in Table 1, the value of this coefficient is in the range from 0.1 to 0.15.

In this regard, the purpose of the study is to determine ways to reduce grain damage by gravity devices.

3. Theoretical research

The structure of grain cleaning and drying complexes for transporting grain material includes gravity devices. The cross-section area of gravity pipes of grain pipelines is selected depending on the capacity: from 50 to 75 t/h - Ø 220 or 200x200 mm cross-section; from 100 to 175 t/h - Ø 300 or 300x300 mm cross-section; from 200 to 350 t/h - Ø 380 or 350x350 mm cross-section; from 500 to 700 t/h - Ø 450.

For grain elevator lines transporting grain, the angles $\alpha$ 36, 45 and 54$^0$ are used. The angles of inclination of gravity pipes to grain dryers are not less than 45$^0$, in all other cases not less than 36$^0$. When transporting rice, sunflower, oats and barley, the angle of inclination of gravity pipes is not less than 45$^0$.

One of the ways to reduce the speed of grain movement and increase the filling coefficient of grain pipelines, without reducing their productivity, in our opinion, is possible by transporting grain material through them in separate portions.

Known devices [8] for transporting bulk and lumpy materials, which provide for the movement of the transported material in a continuous flow with braking, do not allow reducing the speed of movement of the material below 3 m/s.

The device [9], designed for batch movement of cargo through pipes, is characterized by the complexity of kinematic coupling in the drive of individual valves located inside the pipe. In addition, this design includes a special device for the formation of certain amounts of material portions.

In the device (Fig.1) portion of the movement of the grain material is due to the fact that inside thermoprofile 1 at a distance $l$ from each other spring-loaded valves 2 are installed, they are rigidly secured to the axles 4, which are connected with the levers 3. The springs 5 are attached to the levers axes below the center of gravity of the damper preload.
In this device, to ensure the portioning movement of bulk material, the dampers located inside the grain pipeline are not kinematically connected, and do not require additional devices for forming separate portions of material.

Portioned movement of grain along the grain pipeline is carried out in the following way. In the initial position, when the transported material is not fed to the grain pipeline, all the flaps are in the closed position. When the grain (material) is fed to the first flap, the grain begins to accumulate until its pressure and the pressure of the continuously fed grain flow overcomes the resistance of the prestretched springs of this flap. Since the springs are attached to the levers of the axes below the center of gravity of the flap, the latter turns (overturns) and passes the accumulated portion of grain in front of it to the next flap. The pressure on the first flap is reduced by the amount of the missed portion of grain and due to the force of the stretched springs 5, overcoming the resistance of the continuously moving grain flow, it will close. Stop in the form of a visor 6, directs the flow of grain below the upper edge of the flap, preventing pinching of grain between the upper part of the cross section of the pipe and the upper edge of the flap when it is closed. Subsequent flaps 2 accept the portion of grain that has passed through the first flap and open under its pressure in turn. This is also facilitated by the fact that the distance between the flaps is equal to or greater than l, which allows only one flap to open when the others are closed.

Retrofitting of standard gravity flows with such devices allowed reducing the damage capacity by more than a half.

However, in our opinion, this design has a disadvantage, which is manifested in the fact that the flow is counteracted by a spring mechanism, which is known to be subject to fatigue wear, resulting in under-closing of the dampers and the appearance of instability in the formation of portions, which in turn will affect the increase in damage to the grain by pinching it between the edge and the casing.

The design (Fig. 2) [10] makes it possible to increase the reliability of the operation of the dampers, not by using a comparison mechanism with the elastic force of the springs, but with the gravity of the loads.

The material accumulated from the first feeder 2 to the valve until its pressure and the pressure to continuously feed the material flow will not overcome the resistance of the counter-torque generated by the load 6 and not dropping the flap 2. The material goes to the next valve, the pressure at the first valve will be reduced by the amount of the omitted portions of the grain due to the counter-torque generated by the load weight 5, overcoming the resistance of a continuously moving stream, the first valve closes. The stop in the form of a visor 8 directs the flow of material below the upper edge of the flap. The subsequent flaps 2 accept the portion of material that has passed through the first flap 2 and open in turn
under its pressure.

Figure 2. Grain pipeline with cargo flaps: 1-grain pipeline; 2-flap; 3-lever; 4 – flap axis; 5-load weight axis; 6 – load weight; 7 – hinge; 8 – visor.

The distance between the flaps is determined from the condition that when a portion of grain moves from the flap to the flap, the speed of its movement does not exceed the critical \( v_{cr} \), determined in accordance with the type of grain material.

To determine the distance between the flaps, we use the kinetic energy change theorem and the calculation scheme shown in Fig. 3.

\[
T - T_0 = \sum A(F_{out})
\]  

(2)

where \( T_0 \) and \( T \) are the initial and final values of the kinetic energy of a body, for the case with zero initial velocity \( T_0=0; \sum A(F_{out}) \) is the sum of the works of external forces acting on the body.

The kinetic energy of a body (an element of grain mass) is determined from the expression

\[
T = \frac{mv^2}{2}
\]

(3)

The work of gravity is defined as

\[
A(m\vec{g}) = mgl \sin \alpha
\]

(4)

The work of the friction force

\[
A(F_{fr}) = F_{fr}l = fNl = fmgl \cos \alpha
\]

(5)

In these expressions \( l \) is the length of the grain pipeline section between the flaps, m; \( m \) is the weight of the grain mass element, kg; \( N \) is a normal reaction of the bottom of the grain pipeline, N; \( \alpha \) is the angle of the pipe (grain pipeline) to the horizon, deg.; \( f \) is the coefficient of friction of the sliding particle on the plane; \( v \) is the speed of the grain mass element, m/s; \( g \) is the acceleration of gravity, m/s\(^2\).

Substituting expressions (3), (4), (5) into (2) we get

\[
\frac{mv^2}{2} = mgl \sin \alpha - fmgl \cos \alpha
\]
Figure 3. The forces acting on the element of the grain mass.

Then the speed at the end of the path is

$$v = \sqrt{2gl \left( \sin \alpha - f \cos \alpha \right)}$$  \hspace{1cm} (6)

Distance between flaps is

$$l = \frac{v_{\text{critical}}^2}{2g(\sin \alpha - f \cos \alpha)}$$  \hspace{1cm} (7)

The distance from the bucket elevator to the first flap should be reduced, because the bucket elevator gives the initial velocity $v_0$ to the grain stream, which is approximately equal to the speed of the bucket belt. According to [10], $v_0$ is equal to the bucket belt speed. Then, expression (7) will take the form

$$l_1 = \frac{v_{\text{critical}}^2 - v_0^2}{2g(\sin \alpha - f \cos \alpha)}$$  \hspace{1cm} (8)

The distance to the first flap and between them at $\alpha = 45^0$: $v_{\text{critical}} = 4.5m/s$; $v_0 = 2m/s$; $f = 0.3$ respectively equal 1.7m and 2.1m.

When the grain moves through an open flap, the grain portion must not prevent it from closing

$$l_p \leq l - h$$  \hspace{1cm} (9)

The mass of the grain portion located in front of the first flap

$$m_p = \gamma l_p S$$  \hspace{1cm} (10)

here $\gamma$ – the specific mass of grain, kg/m$^3$. $S$ – cross-sectional area of the grain pipeline, m$^2$.

Thus, for the above data, at $\gamma=750$kg/m$^3$ and $S=0.0176$ m$^2$, $h=0.15$ m is the mass of the grain portion at the first flap

$$m_p = 750 \cdot (1.7 - 0.15) \cdot 0.0176 \approx 20$$ kg

The time when the grain is located in front of the first flap with the performance of the grain cleaning complex $Q=20t/h$ (5.55 kg/s) will be

$$t = \frac{m_p}{Q} = \frac{20}{5.55} \approx 4$$ s

The specific weight of grain largely depends not only on its type, but also on humidity. So if the humidity of barley is 15%, then its volume mass is 750kg/m$^3$, while at 20% humidity it is 700kg/m$^3$, therefore, the mass of grain before the first flap will be about 7% less. Therefore, for reliable operation of the device, it is necessary to adjust the value of the counteracting moment by changing the position of the load 6 on the cargo axis 5 (Fig. 2).

4. Experimental result

Research was carried out on barley of the Omsk 95 variety with a grain humidity of $W = 17.6\%$ when loading bucket elevator $Q = 1.2$ kg/s. In the experiments, the TKN-10 bucket elevator was used, with a replaceable grain line installed at an angle of $\alpha = 45^0$. The serial grain pipeline with a cross-section diameter of 0.15 m and a total length of $L = 4$ m was changed to an experimental one with gravity
dampers with a cross-section of 0.16×0.16 m. In the experimental grain pipeline, the flaps inside the pipe were placed at a distance of \( l = 2.1 \) m from each other. The distance from the first flap to the upper head of the bucket elevator \( l_1 = 1.7 \) m.

The experiments were performed three times over. In each series of experiments, samples for the analysis of damage in the grain were taken in the source material and after 1, 5 and 20 passes through the bucket elevator and the grain pipeline. The experimental material obtained as a result of the experiments is shown in table 2.

**Table 2. Damage to grain by bucket elevator with serial and experimental grain pipelines**

| Bucket belt speed \( v_0 \), m/s | Number of passes | Total mechanical damage index, \( \delta_{\text{damages}} \), % | \( \beta \) |
|---------------------------------|----------------|---------------------------------|-------|
| 1.27                            | 0              | 34.0                            | 1.57  | 0.48  |
|                                 | 1              | 38.3                            |       |       |
|                                 | 5              | 51.8                            |       |       |
|                                 | 20             | 77.9                            |       |       |
| 0.94                            | 0              | 34.3                            | 1.32  | 0.46  |
|                                 | 1              | 37.9                            |       |       |
|                                 | 5              | 49.8                            |       |       |
|                                 | 20             | 74.3                            |       |       |
| The bucket elevator with serial grain pipeline | | | | |
| 1.27                            | 0              | 34.4                            | 1.21  | 0.24  |
|                                 | 1              | 38.7                            |       |       |
|                                 | 5              | 48.9                            |       |       |
|                                 | 20             | 63.5                            |       |       |
| 0.94                            | 0              | 33.5                            | 0.98  | 0.23  |
|                                 | 1              | 34.3                            |       |       |
|                                 | 5              | 44.5                            |       |       |
|                                 | 20             | 59.9                            |       |       |

There is a decrease in the index of mechanical damage to grain for bucket elevator with an experimental grain pipeline. With a twenty-fold pass, depending on the speed of the bucket belt, this difference is more than 15%.

From the results of research, it follows that the damaging capacity of the grain pipeline with gravity dampers in comparison with the serial one is reduced by two times and is 0.23 – 0.24 units.

5. Conclusion

The speed of the grain mass in the proposed portioned grain pipeline does not exceed 2.5 m/s, which significantly reduces its damaging ability.

The use of batch grain pipelines with the same performance allows you to reduce their damaging capacity twice.

The use of a combined transport device bucket elevator and grain pipeline allows reducing the total index of mechanical damage by more than 15%.

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