WORKING EFFICIENCY OF SPIRAL CONVEYOR IN TRANSPORTATION OF MIXED FEED

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Abstract. The use of spiral conveyors is a comparatively new and progressive solution in transportation of mixed feed. The article contains theoretical calculation of the conveyor working efficiency, and the results of laboratory studies where the bench-mark data necessary for the constructive calculation are defined and the correspondence examination of theoretical objectives of the conveyor performance is performed.

Key words: spiral conveyor, working efficiency, filling coefficient.

Introduction

Mixed feed is very important in feeding of domestic animals. Usually it is prepared in a fine or granulated shape and stored in special towers, which are constructed near cow sheds. Rope-plate, chain-plate, and spiral type conveyors are used for transporting the feed to feed distribution places installed in cow sheds.

Especially popular in recent years spiral conveyors have become because they in comparison with others have a more common construction and assembly, possibility to curve the conveyor to one or another side in order to change the transportation direction and comparatively small purchase costs. In Latvia, however, there is no sufficient experience accumulated. Therefore, some shortcomings of the assembly and exploitation are possible and they were studied in our previous work [1].

The aim of the present article is to clarify the working efficiency of spiral conveyors in order to specify their theoretical calculation when using mixed feed.

Methods and materials

The calculation of exploitation parameters of spiral conveyors is discussed in several literary sources [2-4]. It is established that their working efficiency depends on the geometrical parameters of the conveyor, rotation number of spiral, peculiarities of conveyor usage (placement pitch, crook radius, filling level) and qualities of transported feed.

In general the working efficiency of spiral conveyors is calculated by formula [2]

$$Q = 3600 \cdot k_r \cdot F_d \cdot v_{z.vid} \cdot \rho \tag{1}$$

where Q – efficiency of spiral conveyor, kg·h^{-1};
k_r – coefficient of working efficiency;
F_d – internal cross section area of flexible pipeline of conveyor, m^2;
$v_{z.vid}$ – average going of material towards the direction of conveyor axis, m·s^{-1};
ρ – volumetric mass of movable material, kg·m^{-3}.

In several literary sources however more precise interpretation of this formula is given.

The working efficiency of a spiral conveyor by Uzkliņģis [2]

$$Q = \rho \frac{\pi \cdot d^2}{4} \cdot s \cdot \frac{n}{60} \cdot \frac{D_c^{\,2} - d_s^{\,2} / \sin\alpha}{D_c^{\,2}} \cdot \frac{\cos\alpha \cdot \cos(\alpha \cdot \mu)}{\cos\mu} \tag{2}$$

where D_c, – internal diameter of pipeline cover, m;
d – external diameter of spiral, m;
d_s – internal diameter of spiral, m;
μ – angle of load (feed) friction through the surface of spiral winding;
s – spiral step, m;
n – number of spiral revolutions per minute;
α – angle of spiral winding.

The angle of the spiral winding is calculable by the coherency [2]

$$\alpha = \mathrm{arctg}\frac{s}{\pi \cdot D} \tag{3}$$

The working efficiency of a spiral conveyor by Grigorjevs [3]

$$Q = \frac{3600 \cdot \pi}{4} \cdot \left(D_c^2 - \frac{d^2}{\sin\alpha} \right) \cdot \frac{d^2}{D_c^2} \cdot v_{z.vid} \cdot \rho \tag{4}$$

But by using the Meļņikov's registration the productivity of the conveyor may be established by considering the coefficient of the conveyor filling [4].

$$Q = \frac{\pi \cdot D_c^2}{4} \cdot s \cdot \rho \frac{\omega}{2\pi} \cdot \varphi \cdot \varphi_s \tag{5}$$

where D_a – internal diameter of cover, m;
ω – angular speed of spiral spinning, s^{-1};
φ – coefficient of filling;
φ_s – coefficient which considers placement pitch.

When comparing all three formulas of the working efficiency of spiral conveyors, it is obvious that in our case none of these formulas may be used. Formula (2) is not applied because instead of round cross-section spirals nowadays orthogonal cross-section spirals are used. Whereas in formula (4) the average going of feed movement is included which the same as the working efficiency is unknown value. But in formula (5) a spiral of the conveyor which reduces the productive capacity of the conveyor is not considered. Therefore, for calculation of the working efficiency of the spiral conveyor both theoretical and experimental studies were necessary.

The experimental studies were performed in a laboratory where there is a spiral conveyor test bench installed. In these studies we defined the actual working efficiency of the conveyor as well as the coefficient of the conveyor pipeline filling.

For the studies we used granulated mixed feed which is produced in "Saldus labība" Ltd. and is used for feeding milk cows on the training and research farm Vecauce of the Latvia University of Agriculture in the dairy cow complex "Līgotnes".

The methodology of the experimental studies was as follows.

- Load the conveyor and determine its productivity Q_1.
- Discharge all feed from the conveyor, weigh it and determine the total mass of feed.
- Determine the mass of capacity of the feed used for the studies ρ.
- Calculate the coefficient of the conveyor filling φ by applying the capacity of the discharged feed towards the useful capacity of the conveyor pipeline, i.e. the capacity of the pipeline from which the occupied capacity of the spiral is deducted.
- Calculate the theoretical productivity of the conveyor Q_t as well as determine its theoretical filling coefficient φ_t.
- Compare the experimental and theoretical data.

Research results

The constructive formation of the spiral conveyor filling end is shown in Figure 1.

As it is seen in the figure in the place of filling in the middle of the spiral a mandrel is located which serves as a bearing spindle. Therefore, the spiral conveyor transforms in this place into the snail-conveyer, and in the split 1-1 feed may move by the area

$$F_{d1} = F_a - F_s - F_{sp} \tag{6}$$

where F_{a1} – area of conveyor working area in cross section 1-1;
F_a – internal area of cross section of conveyor pipeline (cover);
F_s – occupied area of cross section of mandrel;
F_{sp} – occupied area of cross section of spiral.

Whereas in the split 2-2 the area of conveyor working area will be

$$F_{d2} = F_a - F_{sp} \tag{7}$$

Consequently the going area of feed by the split 2-2 is greater than 1-1, but the moving is approximately similar in both of these sections for it is defined by the step of the spiral *s* and revolution amount *n*. Therefore, the working efficiency of the conveyor depends on the intensity of feed going by the split 1-1, and it may be calculated by the formula (1).

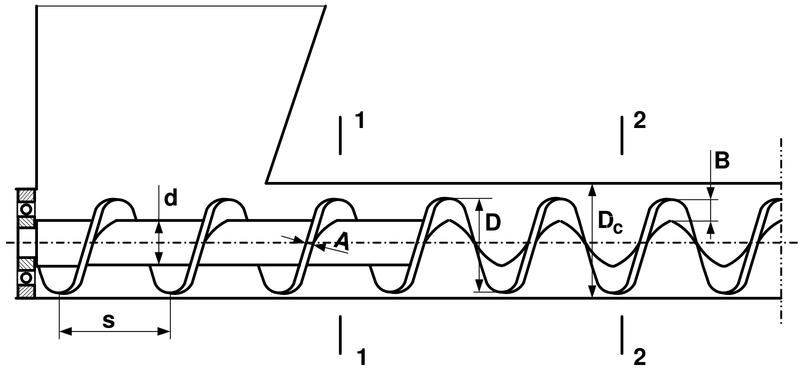

Fig. 1. **The scheme of the end of the conveyor filler**
(explanation of the symbols used in the figure is given in the description below)

If the working coefficient is eliminated then

$$Q_1 = \left(F_a - F_s - F_{sp}\right) \cdot v \cdot \rho \tag{8}$$

or

$$Q_1 = \left(\frac{\pi \cdot D_c^2}{4} - \frac{\pi \cdot d_s^2}{4} - F_{sp}\right) \cdot s \cdot n \cdot \rho \tag{9}$$

$$\text{or } Q_1 = \frac{\pi \cdot s \cdot n \cdot \rho}{4} \cdot \left(D_c^2 - d_s^2\right) - F_{sp} \cdot s \cdot n \cdot \rho \tag{10}$$

where d_s – diameter of mandrel, m;
v – average going of feed, $m \cdot s^{-1}$;
s – step of conveyor spiral, m;
n – number of revolutions of conveyor spiral, s^{-1}.

But

$$F_{sp} \cdot s = V_{sp} \tag{11}$$

where V_{sp} – the occupied capacity of the spiral in the length of its one winding step.

This capacity may be calculated as the multiplication of the spiral cross section with the respective length of the spiral symmetry axis.

If the symmetry axis of the spiral winding is shown in the layout (Figure 2), it is possible to calculate the length of the symmetry axis l_{sp} by the formula

$$l_{sp} = \frac{s}{\sin\alpha} \tag{12}$$

where α – angle of spiral rise.

But

$$V_{sp} = l_{sp} \cdot A \cdot B = \frac{s \cdot A \cdot B}{\sin\alpha} \tag{13}$$

where A; B – height and width of spiral side, m.

Thus the calculation formula of the working efficiency of the spiral conveyor (10) obtains the form

$$Q_1 = Q_t = \frac{\pi \cdot s \cdot n \cdot \rho}{4} \cdot (D_c^2 - d_s^2) - \frac{s \cdot n \cdot \rho \cdot A \cdot B}{\sin \alpha} \tag{14}$$

where Q_t – theoretical working efficiency of spiral conveyor, kg·s^{-1}.

In order to calculate the theoretical efficiency of the conveyor it is necessary to define the feed compactness by experimental methods. In the laboratory we defined that the compactness of mixed feed is 659 kg·m^{-3} (with relative standard error 0.76 %).

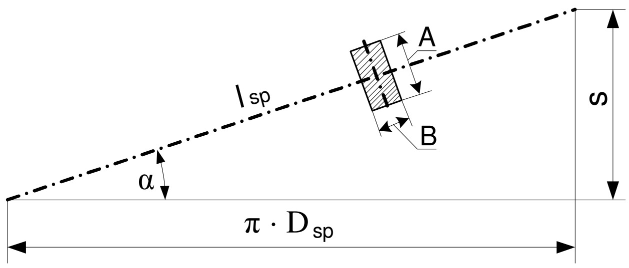

Fig. 2. **The layout of symmetry axis of one spiral winding**

Information about theoretically and experimentally defined working efficiency of the spiral conveyor is summarized in Table 1.

Table 1

Theoretical and experimental working efficiency of spiral conveyor

Calculation method	Average working efficiency, kg·s^{-1}	Standard deviation, kg·s^{-1}	Relative standard error, %
Theoretical	0.503	0.005	0.67
Experimental	0.478	0.005	0.40

As the table shows, the study results have excellent representation. The theoretical working efficiency however is greater than the experimental by about 5 %. The difference of the obtained results may be explained by the lagging of feed flow from its theoretical moving because the conveyor spiral does not take all internal area of the cross section of the pipeline, therefore over-pouring of feed through respective gaps is possible. In addition it may be forecasted that the intensity of this over-pouring depends on the conveyor pitch angle. Therefore, the formula (14) may be supplemented with the coefficient k_v

$$Q_f = k_v \cdot \frac{\pi \cdot s \cdot n \cdot \rho}{4} \cdot (D_c^2 - d_s^2) - k_v \cdot \frac{s \cdot n \cdot \rho \cdot A \cdot B}{\sin \alpha} \tag{15}$$

where k_v – coefficient which observes difference between actual and theoretical going of feed.

$$k_v = \frac{Q_f}{Q_t} \tag{16}$$

In accordance with our studies when the experimental station is used at the horizontal position of the spiral conveyor, the filling coefficient k_v is within 0.930 and 0.975.

Using Figure 1 it is possible to calculate also the coefficient of the spiral conveyor filling φ. Taking into account that the feed flow intensity through the areas of cross sections 1-1 and 2-2 is equal, but the useful area of the conveyor in the cross section 2-2 is φ times greater (than part taken by the mandrel)

$$\varphi = \frac{F_1}{F_2} = \frac{F_a - F_s - F_{sp}}{F_a - F_{sp}} \tag{17}$$

or calculating by the capacity on the length of one step of spiral

$$\varphi = \frac{V_1}{V_2} = \frac{F_a \cdot s - F_s \cdot s - \dfrac{A \cdot B \cdot s}{\sin\alpha}}{F_a \cdot s - \dfrac{A \cdot B \cdot s}{\sin\alpha}} = \frac{F_a - F_s - \dfrac{A \cdot B}{\sin\alpha}}{F_a - \dfrac{A \cdot B}{\sin\alpha}} \tag{18}$$

where V_1; V_2 – useful capacity of conveyor in the length of one step of spiral in the split 1-1 and accordingly in 2-2.

During rotation the spiral of the conveyor not only moves feed onwards but tries to produce the rotation movement to it as well. But taking into account that the pipeline is not full it will over-pour from one side to another making natural spillage angle. Therefore, the unfilled part in the conveyor pipeline split 2-2 will have a segment shape.

The area of this segment is equal with the area taken by the mandrel

$$F_{seg} = F_s = \frac{\pi \cdot d^2}{4} \tag{19}$$

Or as a rough guide according to the segment shape [6]

$$F_{seg} \approx \frac{2}{3} \cdot l_s \cdot h_s \tag{20}$$

where l_s – width of segment base, m;
h_s – segment length, m.

The last formula holds both the calculable value F_{seg}, and two unknown values: segment length h_s and base width l_s. These values were defined graphically by using computer program AutoCAD 2010. Thus we found out that in our case h_s = 22.5 mm but l_s = 73 mm. It means that in the particular case the conveyor spiral is not completely covered with feed. Its prominence above the layer of feed is approximately 2.5 mm.

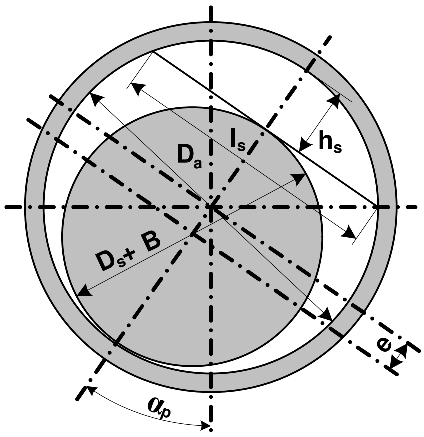

Fig. 4. **The scheme of cross section of spiral conveyor:** e – eccentricity of spiral placement, m; α_p – angle of spiral displacement, explanation of other symbols is given in the description

As it is proved by our theoretical studies the filling coefficient of the cased-pipe of the spiral conveyor is φ = 0.777, but according to the experimental studies this coefficient is defined as 0.788. Therefore, the difference is only 1.4 %. In turn, the maximal possible efficiency of the conveyor may be reached if the spiral is covered with the feed fully and it corresponds to the filling coefficient φ = 0.8112. The filling of conveyor cross-section and its influence upon working efficiency of conveyor however requires additional studies.

Conclusions

1. This new formula (17) may be used for calculation of the working efficiency of spiral conveyors. If the conveyor is set horizontally and it does not have a curve, the coefficient k_v is 0.95. This coefficient is included in formula and observes a correlation between the actual and theoretical going.
2. The filling coefficient of the covered-pipe of the experimental conveyor is approximately 0.78 (theoretically obtained 0.777, but experimentally – 0.788). For the conveyor spiral to be in the feed fully this coefficient must be 0.8112.

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