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DIRECTED LOADING OF THE HIGH-SPEED SCREW CONVEYOR FROM THE BUNKER

Roman Rogatynskyi; Taras Peleshok; Olena Rogatynska; Pavlo Les’kiv

Ternopil Ivan Puluj National Technical University, Ternopil, Ukraine

Summary. *The results of the investigations of high-speed conveyor loading with bulk cargo are given. It is established that directional compressed flow produces dynamic pressure resisting the centrifugal motion of the load during its rotation and ensures the efficient filling of the screw conveyor operating space. Parameters of the guiding platform which application provides the feed velocity flow corresponding to the axial velocity of cargo transportation by the screw conveyor at the assigned coefficient of its filling is substantiated.*

Key words: *bulk cargo, bunker, screw conveyors, loading, directional flow.*

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Statement of the problem. The stability of transport-technological systems for bulk materials transportation is determined by the reliability and stability of the bunkers operation [1, 2]. This applies especially screw conveyors (SC), where their fill factor and, relatively, effectiveness are generated in the loading area and depend on both loading hole parameters and operating modes of the SC [3, 4]. For high-speed SC, at their bunker loading, achievement of the fill factor rational values and ensuring the calculated effectiveness is complicated by the effect of centrifugal forces occurring during the rotation of the screw operating element. It is possible to reduce the centrifugal forces influence and increase the screw conveyor fill factor by generating directional flow, which vertical velocity component resists the centrifugal forces occurring during the screw conveyor rotation and the axial component corresponds to the speed of the bulk transportation by screw conveyor. Therefore, the investigation of the processes of high-speed conveyor directional loading resulting in SC effective loading is important.

Analysis of the available investigation results. To provide the given coefficient of high-speed SC filling the forced loading systems, particularly, feeders of various types are used [1, 4]. However, their application significantly increases the cost of bulk transportation and can be suggested for vertical screw conveyors loading. For horizontal screw conveyors loading it is efficient to use gravity loading systems where the bulk after exiting from the bunker acquires certain kinematic energy [3, 4, 5, 7]. At the direct bulk drop, the increase of particles velocity height wise the flow causes its dilution preventing the effective high-speed SC loading [5, 6, 7, 8].

The objective of the paper is to provide bunker loading of high-speed SCs by generating directional compressed flow of the bulk cargo with high kinetic energy of the flow in order to resist the centrifugal forces from the SC rotating operating element complicating their filling with bulk cargo.

Statement of the problem. Such compression can be reached by application of inclined guiding platforms installed in the flow path [9]. Moreover, the use of guiding platforms makes it possible to coordinate the horizontal component of the SC filling velocity with the axial speed of cargo transportation.

Let us consider the bulk cargo outflow from the bunker with the implementation of compressed directional flow, Fig. 1. We choose coordinate system Oy in such a way that the

Corresponding author: Rogatynskyi Roman; e-mail: rogatynskyi@gmail.com axis Oy is directed horizontally towards the directional outflow, the axis Oz – upward vertically, and the origin of coordinates O is placed at the beginning of the outflow hole outlet at point A_1, Fig. 2.

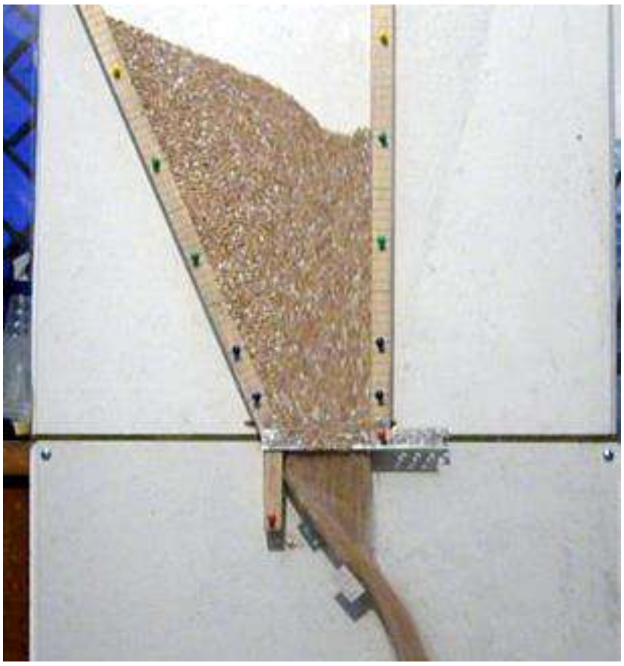

Figure 1. Implementation of directional compressed flow

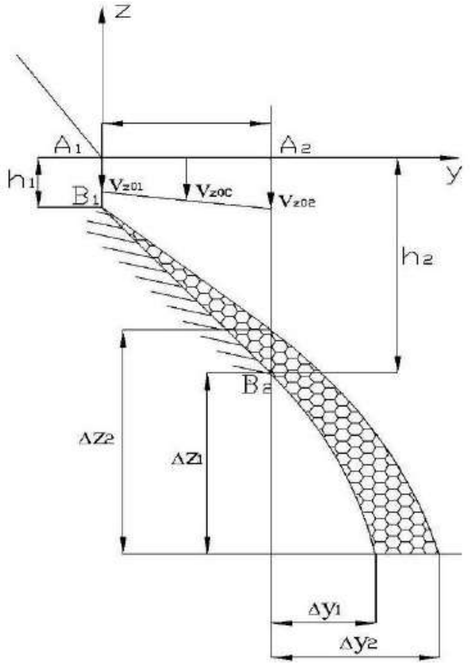

Figure 2. Diagram for calculation of the of compressed flow implementation using guiding platform

Then the coordinates of the outlet edges are $A_1(0;0)$ and $A_2(b;0)$, where b is the outlet length.

Let us assume that at the point A_1 the initial velocity of the exiting from the bunker is $v_{01} = v_{z01}$, and at the point A_2, $v_{02} = v_{z02}$ relatively.

If we accept the linear distribution of velocities along the hole length, then the velocity change of the bulk cargo outlet is expressed by dependence

$$v_{z0}(y) = v_{z01} + (v_{z02} - v_{z01}) \cdot y / b\,. \tag{1}$$

The part of the cargo, which at the moment of intersection of the discharge hole (A_1A_2) of the bunker has the acceleration speed v_{z0i} resulting in its velocity change in time according to the dependence

$$v_{zi}(t) = v_{z0i} + gt\,, \tag{2}$$

where g – is gravitational acceleration.

The equation of the guiding platform for cargo direction towards its feed by conveyor in the coordinate system yOz is as follows

$$z(y) = -h_1 - (H - h) \cdot y \operatorname{tg}\alpha = -(h_1 + y \operatorname{tg}\alpha_n)\,, \tag{3}$$

where h_1 and h_2 – is the smallest and largest distance from the bunker hole to the edges of the guiding platform; α_n is the inclination angle of the guiding platform, $\mathrm{tg}\,\alpha_n = (h_2 - h_1)/b$.

The finite collision velocity of i-th particle $v_{zi}(y)$ with coordinate y falling to the guiding platform is assigned by its drop height and determined from the condition of kinetic and potential energy equality

$$v_{zi}(y) = \sqrt{v_{z0i}^2 + 2g \cdot h_i(y)}\ . \tag{4}$$

Thus, the distribution of particle velocities along the guiding platform, which we denote as B_1B_2, is described by the dependence

$$v_{zB}(y\ ) = \sqrt{v_{z0}^2(y) + 2g(h_1 + y\ \ \mathrm{tg}\,\alpha_n)}\ . \tag{5}$$

From the known dependence $h = v_0 t + gt^2/2$, we determine the particle flight time from the discharge hole A_1A_2 to the guiding platform B_1B_2

$$t_i = \left(\sqrt{v_{z0i}^2 + 2gh_i} - v_{z0i}\right)/\,g\ . \tag{6}$$

Let us consider the impact of the separated particle in the flow with directional area. Since at free falling the flow of particles is diluted, the flow density decreases and at the initial moment the first particles contact with the surface separately, and the following ones fall onto particles sliding along the guiding platform as continuous flow.

For the case of the flow dropping to the horizontal platform, Fig. 3, the condition of momentum conservation for separated particles is

$$m\bar{v}_{Bi+} - m\bar{v}_{Bi-} = \bar{F}_i \cdot \Delta t_i\,, \tag{7}$$

where $\bar{v}_{Bi-}$ and $\bar{v}_{Bi}$ are vectors of the particle velocity before and after its contact with the platform; $\bar{F}_i$ is average impact force; Δt_i is collision time. When the cargo contacts with the platform without rebound $\bar{v}_{Bi-} = \bar{v}_{zBi}$, $\bar{v}_{Bi+} = \bar{v}_{yBi-} = 0$.

If drop height is low then the preceding particles in the flow are effected by the following ones and we consider that there is continuous impact contact of the flow with platform.

Let us distinguish the cargo volume $\mathrm{d}V$ with the elementary mass $\mathrm{d}m$ and bulk density ρ_0

$$\mathrm{d}m = \rho_0\,\mathrm{d}V = \rho_0\,\mathrm{d}S \cdot \mathrm{d}h\,. \tag{8}$$

The elementary cargo volume $\mathrm{d}V$ with height $\mathrm{d}h = \mathrm{d}z = v_{zB}(y) \cdot \mathrm{d}t$, having mass $\mathrm{d}m = \rho_p\,\mathrm{d}V = \rho\,\mathrm{d}S \cdot \mathrm{d}z$, where ρ_P is the bulk density of the diluted stream passes through the normal line to the flow the platform Δ, with the area $\mathrm{d}S = x\,\mathrm{d}y$ during time $\mathrm{d}t$.

The bulk densities of the compressed and diluted cargo are connected by dependence.

$$\rho_P v_{zB}(y, z) = \rho_0 v_{z0}(y) \tag{9}$$

Hence, taking into account (8), the dependence for determining the cargo bulk flow through the platform area Δ contacting with the guiding platform is

$$\mathrm{d}Q_{m\Delta} = \mathrm{d}m/\mathrm{d}t = \rho_P v_{zB}(x,y)\,\mathrm{d}S \tag{10}$$

For the flow case, equation (7) becomes

$$\bar{v}_{zB}(y)\,\mathrm{d}m = \mathrm{d}\bar{F}_{\Delta}(y)\cdot\mathrm{d}t\,. \tag{11}$$

From the general solution of (10) and (11) and taking into account (9) we get

$$\mathrm{d}F_{\Delta} = \rho_0 v_{z0}(y)\cdot v_{zB}(y)\,\mathrm{d}S\,. \tag{11}$$

Considering (1) and (5), the normal stresses causing the cargo flow to the horizontal platform, located from the bunker hole at a distance $h = h_1 = h_2$, from which the bulk cargo flows at a speed v_{z0}, are

$$\sigma_S(y) = \rho_0 \cdot v_{z0}(y)\sqrt{v_{z0}^2(y) + 2gh}\,. \tag{12}$$

Thus, for $v_{z0}(y) = v_{z0} = \mathrm{const}$ the impact force on the horizontal platform is

$$F_z = \rho_0 Q\,\sqrt{v_{z0}^2 + 2gh}\,, \tag{13}$$

where Q is volume flow, $Q = \mathrm{d}V/\mathrm{d}t = v_{z0}S$.

Let us consider the flow particles collision from the inclined guiding platform B_1B_2 (Fig. 2, Fig. 4).

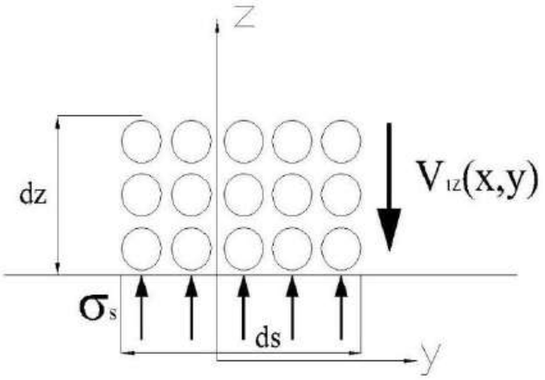

Figure 3. Diagram for stress determination during the cargo drop to horizontal platform

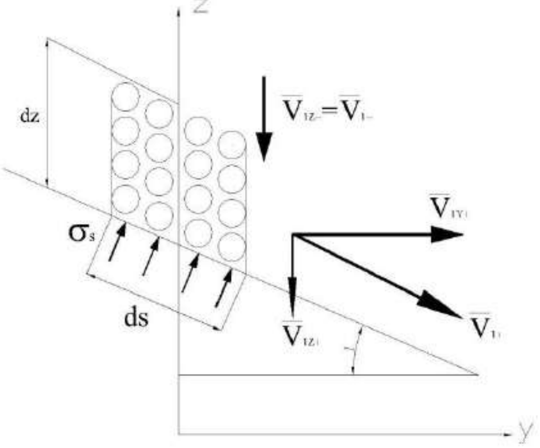

Figure 4. Diagram for determination of stresses and velocities during the cargo drop to inclined directional platform

The condition of the momentum conservation for the elementary mass $\mathrm{d}m$ during the contact interaction is

$$\mathrm{d}m[\bar{v}_{B-}(y) - \bar{v}_{B+}(y)] = \mathrm{d}\bar{F}_{\Delta}\cdot\mathrm{d}t = \left(\mathrm{d}\bar{F}_n + \mathrm{d}\bar{F}_{\tau}\right)\mathrm{d}t\,, \tag{14}$$

where $\mathrm{d}\,\overline{F}_n$ and $\mathrm{d}\,\overline{F}_\tau$ are relatively normal and tangential force components from the impact interaction of the mass $\mathrm{d}\,m$ with the platform. Suppose the instantaneous friction coefficient is equal μ_y. Then $\mathrm{d}\,F_\tau = \mu_y\,\mathrm{d}\,F_n$.

Let us assume that there is no bounce of particles from the guiding surface under conditions of continuous flow. Therefore

$$\bar{v}_{yB+} = v_{B+}\cdot\cos\alpha\cdot\bar{j}\,;\;\bar{v}_{zB+} = -v_{B+}\cdot\sin\alpha\cdot\bar{k}\,.$$

The projections of the normal and tangential components of the impact force on the coordinate axis yOz are $\mathrm{d}\,F_{ny} = \mathrm{d}\,F_n\cdot\sin\alpha$, $\mathrm{d}\,F_{nz} = \mathrm{d}\,F_n\cdot\cos\alpha$; $\mathrm{d}\,F_{\tau y} = -\mu_y\,\mathrm{d}\,F_n\cdot\cos\alpha$; $\mathrm{d}\,F_{\tau z} = \mu_y\,\mathrm{d}\,F_n\sin\alpha$.

Thus, the vector equation of momentum conservation (14) in case of decomposition into the coordinate axis will is as follows

$$\sum Y:\left(-v_{B+}\cos\alpha\right)\cdot\mathrm{d}\,m = \left(\mathrm{d}\,F_n\sin\alpha - \mu_y\,\mathrm{d}\,F_n\cos\alpha\right)\cdot\mathrm{d}\,t\,; \tag{15}$$

$$\sum Z:\left(v_{B+}\sin\alpha + v_{B-}\right)\cdot\mathrm{d}\,m = \left(\mathrm{d}\,F_n\cos\alpha + \mu_y\,\mathrm{d}\,F_n\sin\alpha\right)\cdot\mathrm{d}\,t\,.$$

From the system (15) we get

$$\mathrm{d}\,F_n\cdot = v_{B-}\cos\alpha\,\mathrm{d}\,m/\mathrm{d}\,t\,. \tag{16}$$

The elementary flow mass with the height $\mathrm{d}\,z$ dropping to the inclined platform $\mathrm{d}\,S_B = \mathrm{d}\,S/\cos\alpha$ is $\mathrm{d}\,m = \rho_1\,\mathrm{d}\,z\cdot\mathrm{d}\,S_B\cdot\cos\alpha$.

Thus, during the interaction of the cargo incident flow from the guiding platform inclined at angle α, the normal stresses on it equal

$$\sigma_S(y) = \rho_0 v_{z0} v_{zB}/\cos^2\alpha = \rho_0 v_{z0}\sqrt{v_{z0}^2(y) + 2g(h_1 + y\,\mathrm{tg}\,\alpha)}\,/\cos^2\alpha\,. \tag{17}$$

The impact strength on the inclined platform at $v_{z0}(y) = v_{z0} = \mathrm{const}$ is

$$F_n = \rho_0 Q\;[\int_0^b\sqrt{v_{z0}^2 + 2g(h_1 + y\,\mathrm{tg}\,\alpha)}\,\mathrm{d}\,y]/(b\cos\alpha)\,. \tag{18}$$

The particles velocity distribution after impact contact with the inclined platform is

$$v_n(y) = \sqrt{v_{z0}^2(y) + 2g(h_1 + y\,\mathrm{tg}\,\alpha)}\cdot\left(\sin\alpha - \mu_n\cos\alpha\right). \tag{19}$$

Let us assume that the selected element of the flow with mass $\mathrm{d}\,m$ and width $\mathrm{d}\,y_0$ starts its movement from the limiting point B_1 of the inclined platform with the coordinate $y = 0$.

Its initial velocity is

$$v_n(0) = \sqrt{v_{z01}^2 + 2gh_1}\cdot\left(\sin\alpha - \mu_n\cos\alpha\right). \tag{20}$$

When moving along the inclined platform the selected element gains acceleration and its travelling speed at free slipping movement is determined from the energy conservation condition

$$\mathrm{d}\,m\left(\frac{v_{ny}^2 - v_{n1}^2}{2}\right) = \Delta h \cdot g\,\mathrm{d}\,m - \frac{\mu_n F_{nB} \cdot y}{\cos\alpha} = y \cdot g\left(\mathrm{tg}\,\alpha - \mu_n\right)\mathrm{d}\,m\,. \tag{21}$$

Thus, the law of cargo velocity change with the initial coordinate y_c along the inclined platform is, Fig. 5,

$$v_n(y_c) = v_{n1}\sqrt{1 + 2k_n y_c g\left(\mathrm{tg}\,\alpha - \mu_n\right)/\,v_{n1}^2}\ , \tag{22}$$

where k_n is the coefficient, taking into account the effect of constant cargo refilling when it moves along the inclined guiding platform $k_n = 0{,}6 - 0{,}7$.

Dependences of the cargo feed velocity to the conveyor and its horizontal component, depending on the guiding platform inclination are shown in Fig. 6.

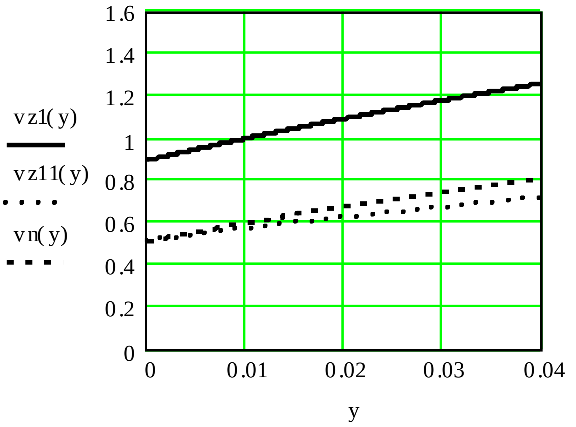

Figure 5. Diagram of velocity distribution during the particles drop on the guiding platform: $v_{z1}(y)$ – before the contact with the platform; $v_{z11}(y)$ – after the contact; $v_n(y)$ – cargo velocity change with the initial coordinate $y = 0$ along the platform, inclined at angle $\alpha = 50^\circ$

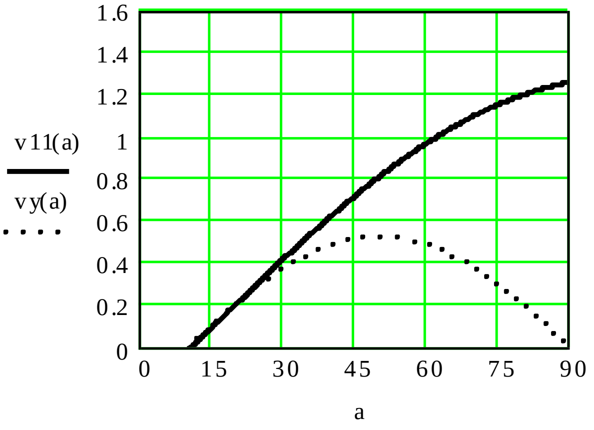

Figure 6. Dependence of the flow velocity change at the outlet from the guiding platform $v_n(b) = v11(a)$ and its horizontal component $v_{ny}(b) = vy(a)$ from the angle of the platform mounting $\alpha = a$ (degrees) at $v_0 = 0{,}2$ m/s, $\mu = 0{,}5$

The limitation of the guiding platform mounting angle follows from dependence (22).

The value of the angle α, in which the horizontal velocity component at the outlet from the platform $v_{ny}(b) = v_n(n) \cdot \cos\alpha_n = \max$ is maximum and is determined by the condition $\mathrm{d}\,v_{ny}\,/\mathrm{d}\,\alpha = 0$ or in expanded form

$$\frac{\mathrm{d}\{\sqrt{v_{z0}^2 + g(h_1 + 2y\,\mathrm{tg}\,\alpha})(\sin\alpha - \mu_n\cos\alpha)\}}{\mathrm{d}\,\alpha} = 0\,. \tag{18}$$

Conclusions. The use of guiding platforms for compression of the cargo drop from the bunker and its direction to the conveyer loading zone providing increase in the loading rate of high-speed screw conveyors and correlation of cargo feed velocity with its transportation velocity is substantiated in this paper.

The dependence of the dynamic pressure on the guiding platform on the outflow rate from the bunker outlet hole and the cargo drop height is determined, control of the cargo feed parameters to the conveyer operating area by the angle the guiding platform inclination depending on the cargo rheological properties is substantiated.

The investigation results form the basis for engineering calculation of the high-speed screw conveyors bunker loading using the directional cargo feed systems.

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НАПРЯМЛЕНЕ ЗАВАНТАЖЕННЯ ШВИДКОХІДНИХ ГВИНТОВИХ КОНВЕЄРІВ З БУНКЕРА

Роман Рогатинський; Тарас Пелешок; Олена Рогатинська; Павло Леськів

Тернопільський національний технічний університет імені Івана Пулюя, Тернопіль, Україна

Резюме. *Розглянуто бункерне завантаження швидкохідних горизонтальних та пологих гвинтових конвеєрів сипким вантажем, в яких, унаслідок дії відцентрових сил від обертання гвинтового робочого органу та розрідження потоку при його вільному падінні, зменшується коефіцієнт заповнення та продуктивність конвеєра. З метою їх підвищення запропоновано розріджений потік вантажу ущільнювати похилою направляючою площадкою та подавати його в зону завантаження зі швидкістю подачі, що узгоджена зі швидкістю транспортування вантажу гвинтовим конвеєром. Із умови збереження імпульсу потоку вантажу визначаємо тиск та силу, які діють на напрямну площадку, та розподіл швидкостей потоку по площадці залежно від продуктивності конвеєра, висоти та кута встановлення площадки. Встановлено, що сила удару вантажу до похилої напрямної площадки прямо пропорційна масовій витраті вантажу, швидкості його зіткнення з площадкою та обернено пропорційна косинусу кута її встановлення. Визначено раціональне значення кута встановлення площадки залежно від коефіцієнта зовнішнього тертя вантажу до поверхні площадки, при якому горизонтальна складова швидкості його сходження з площадки максимальна. Показано, що взаємним розміщенням бункера та напрямної площадки можна регулювати кінематичні параметри потоку та узгоджувати швидкість подачі вантажу зі швидкістю його транспортування швидкохідним гвинтовим конвеєром і тим самим нівелювати дію відцентрових сил від обертання гвинта. Результати досліджень закладають основу для інженерного розрахунку керованого бункерного завантаження високоефективних швидкохідних гвинтових конвеєрів з малою енерго- та матеріалоємністю.*

Ключові слова: *сипкий вантаж, бункер, гвинтові конвеєри, навантаження, спрямований потік.*

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