The combination feeder of a continuous-action loader for the bulk load

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Abstract. The spectrum of construction, industrial, agricultural and other bulk load includes a lot of names that vary in their physical, mechanical and volume-mass characteristics. Continuous-action loaders are developed and constantly improved for bulk load shipping. Their main operating element, which is responsible for the efficiency and power consumption of the drive, is a feeder. The feeder separates or grabs the load from the surface on which the bulk load is stored. It is proposed to use a combination feeder consisting of two operating elements, that will allow to grab the load and transport it simultaneously. The kinematic analysis of the feeder operation and its interaction with the load has been carried out. We have derived the parametric equations of the blade motion when the loader is traveling and the shaft is rotating in the coordinate form. Relying on the length of the blade trajectory, it is presented the expression for the determination of the continuous-action loader with the combination feeder efficiency. The efficiency depends on the physical and mechanical properties of the load, operational and design specifications of the feeder.

Along with cyclical loaders, continuous-action loaders are widely used for loading bulk construction, industrial, agricultural and other loads. These machines are characterized by the continuity of the technological process, high efficiency and low energy consumption of loading [1].

The operating element of a continuous-action loader, that determines its efficiency, is a feeder. Thanks to the feeder, the load is separated, captured and transferred to the transporting operating elements of the loader, followed by unloading into the vehicle [2].

In general, the efficiency of the loader depends on the efficiency of the feeder $Q_n$, the efficiency of the input conveyor $Q_{tr}$, and the efficiency of the subsequent shipping conveyors $Q_n$. To provide non-stop operation, the following condition must be met:

$$Q_n \geq \cdots \geq Q_{tr} \geq Q_n$$ (1)

The design and operating modes of the feeder must correspond to the physical and mechanical and volume-mass properties of the load. It is proposed to use a combination feeder (figure 1) for shipping bulk load [3].

The combination feeder consists of a shaft with blades (figure 2, figure 3) and a chain conveyor 3 (figure 1). The chain conveyor has got two hauling chains, interconnected with plates, and support rollers 2, preventing the slack of the conveyor [4].
The feeder operates in the following way: the shaft with blades grabs the load, moves it in a circular way and unloads on the conveyor. The blades move inside the chain conveyor when unloading. The conveyor, without any additional resistances, moves the load to the subsequent transporting elements or to the vehicle for unloading [5].

![Figure 1. The combination feeder: 1 – a shaft with blades; 2 – support rollers; 3 – a chain conveyor; 4 – a sprocket-wheel.](image1)

This design and technological scheme of the feeder has got a feature, namely, the shaft with the blades and the chain conveyor are combined into one operating element, besides, the structure design implements the principle of transferring the load on the hauling element, that requires less energy [6].

![Figure 2. The shaft with blades.](image2)

To determine the efficiency of the combination feeder, a kinematic analysis of its operation was carried out and the laws of motion of the operating elements were determined [7].

When operating, the loader moves frontally figure 1 at a speed of \(v_n\). The shaft with blades rotates at a rotating speed \(\omega_n\). Since the structurally driven sprocket-wheel and the shaft with blades have got a common axle, than the rotating speed \(\omega_n\) equals to \(\omega_{\text{sw}}\).
Each point on the blade performs a relative motion with the speed:

\[ v_r = 0.5 \omega_a D_a = \pi n_a D_a, \]  

where \( D_a \) – the diameter of the shaft with blades, m;  
\( \omega_a = 2 \pi n_a \) – rotating speed, rev/s;  
\( n_a \) – rotating frequency of the shaft with blades, s\(^{-1}\).

The absolute speed equals to:

\[ v_a = \left( v_n^2 + v_r^2 - 2 v_n v_r \cos(180 + \omega_a t - \beta_{tp}) \right)^{1/2} \]

\[ \text{Figure 3. The shaft with blades.} \]

With regard to \( \cos\left[180 + (\omega_a t - \beta_{tp})\right] = -\cos(\omega_a t - \beta_{tp}) \) and \( \omega_a t = \varphi \) we get:

\[ v_a = \left[ v_n^2 + (\pi n_a D_a)^2 + 2 v_n \pi n_a D_a \cos(\varphi - \beta_{tp}) \right]^{1/2} \]

where \( \beta_{tp} \) – the angle of chain conveyor setting, degree.

Let us consider the system on the plane \( xOy \). Point \( A \) performs a curvilinear motion around the axle of the shaft with blades [8]. The parametric equations of the motion of Point \( A \) in the coordinate form, while the loader is moving and the shaft with blades is rotating, will have the following form:

\[ x = v_n t + 0.5 D_a \cos \varphi; \quad y = 0.5 D_a \sin \varphi \quad \text{при} \quad \varphi = \varphi_0 + \omega_a t, \]

where \( \varphi \) – the angle of blade rotation, degree;  
\( \varphi_0 \) – the initial angle of blade rotation, degree.

The amount of load \( V_n \), grabbed and moved by the shaft with blades, will depend on the length of the trajectory \( l \), the distance \( S_n \), which the loader moves on with the speed \( \theta_n \) at time \( t \) and the width of the feeder rack \( B \). The length of the trajectory is a distance which the blade covers at time \( t \) from the moment of the contact with the bulk load till its unloading on the chain conveyor [9].

\[ V_n = l S_n B = l \theta_n t B \]

The length of the trajectory of the blade motion is calculated with the use of the formula

\[ l = \int_{t_1}^{t_2} \sqrt{(x'_t)^2 + (y'_t)^2} dt, \]

and it depend on the rotating speed of the shaft with blades and the travelling sped of the loader. In the expression (7) the values \( t_1 \) and \( t_2 \) – respectively, the time of the beginning of the blade contact with the bulk load and the time of unloading the blade, s [10].
By transposing the expression (7), we get

\[ l = \int_{t_1}^{t_2} (u_n^2 + r_n^2 \omega_n^2 - 2u_n r_n \omega_n \sin \varphi)^{1/2} dt \]  \hspace{1cm} (8)

Taking into consideration, that \( \sin \varphi = \cos(\varphi - \pi/2) = \cos \alpha \), where \( \alpha = \varphi_0 - \pi/2 + \omega_a t \); \( da = \omega_a dt \).

The limits of integration \( \alpha(t_2) \) and \( \alpha(t_1) \).

\[ l = \int_{\alpha(t_1)}^{\alpha(t_2)} (u_n^2 + r_n^2 \omega_n^2 - 2u_n r_n \omega_n \cos \alpha)^{1/2} d\alpha, \]  \hspace{1cm} (9)

where

\[ \sqrt{a - b \cos x} \, dx = 2\sqrt{a + b} \left[ \arcsin \left( \frac{(a+b)(1-\cos x)}{2(a-b) \cos x} \right)^{1/2} \right] - \frac{2b \sin x}{\sqrt{a - b \cos x}}. \]

\( E \) – the elliptic integral of the second class; if \( a > b > 0 \) and \( 0 \leq x \leq \pi \) and

\[ a = u_n^2 + r_n^2 \omega_n^2 > 0; \quad b = 2u_n r_n \omega_n > 0; \]
\[ a - b = u_n^2 + r_n^2 \omega_n^2 - 2u_n r_n \omega_n = (u_n - r_n \omega_n)^2 \]

the first condition is always met.

\[ 0 \leq \varphi - \pi/2 \leq \pi \implies \pi/2 \leq \varphi \leq 3 \pi/2. \]

Finally, the length of the trajectory of the blade motion is determined with the use of the expression:

\[ l = \frac{2(\varphi_0 + \omega_a t_2)}{\omega_n} K - \frac{4u_n r_n \omega_n}{\varphi_0 + \omega_a t_2} \left[ -\cos(\varphi_0 + \omega_a t_2) + \cos(\varphi_0 + \omega_a t_1) \right] \]  \hspace{1cm} (10)

where \( K \) – an auxiliary coefficient.

\[ K = E \left( \arcsin \left( \frac{u_n + r_n \omega_n}{u_n + r_n \omega_n} \left[ \frac{1 - \sin(\varphi_0 + \omega_a t_2)}{2(u_n^2 + r_n^2 \omega_n^2 - 2u_n r_n \omega_n \sin(\varphi_0 + \omega_a t_2))} \right]^{1/2} \frac{2 \sqrt{u_n r_n \omega_n}}{u_n + r_n \omega_n} \right) \]

\[ -E \left( \arcsin \left( \frac{u_n + r_n \omega_n}{u_n + r_n \omega_n} \left[ \frac{1 - \sin(\varphi_0 + \omega_a t_1)}{2(u_n^2 + r_n^2 \omega_n^2 - 2u_n r_n \omega_n \sin(\varphi_0 + \omega_a t_1))} \right]^{1/2} \frac{2 \sqrt{u_n r_n \omega_n}}{u_n + r_n \omega_n} \right) \]

As a result, the amount of the load grabbed by the blades is determined as

\[ V_n = v_n t B \]  \hspace{1cm} (11)

Finally, the efficiency of the combination feeder with regard to the physical and mechanical properties of the load, mode and design parameters will be determined as

\[ Q_n = \rho v_n B V_n, \]  \hspace{1cm} (12)

where \( \rho \) - load density, kg/m³.

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