Dynamic method of control of weight of cargo transported by a belt conveyor

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Abstract. The intensification of the transportation processes of mined minerals is one of the key factors in solving the problems of increasing the productivity and competitiveness of the extractive industries. The processes of transportation of mining minerals are associated with their spatial movement by means of belt conveyors. Existing tools for assessing the weight of mining minerals transported by conveyors are based on the use of strain gauge methods and means of control, which allow weighing of mining rocks with acceptable accuracy at a conveyor belt speed of up to 5 m/sec. For conveyors with a high length (more than 10 km), such speed and weighing speed is unacceptable. Therefore, the development of methods and means of controlling the weight of rock transported by a conveyor at high speed is an urgent task. This paper is devoted to the substantiation of the dynamic method of controlling the weight of cargo transported by a belt conveyor based on an assessment of the dynamics of acceleration and deceleration of the rotor of a driving electric motor in steady–state operating conditions.

1. Introduction
Improving the efficiency of mining enterprises is associated, including with an increase in the rate of transportation of rocks by belt conveyors. In accordance with [1], the maximum transport speed can reach 11 m/sec. However, most of the belt scales on the world market can produce a result with an acceptable error at a maximum conveyor speed of 5 m/sec. Thus, today there is a contradiction: on the one hand it can be transported at a speed of up to 11 m/sec, on the other hand we can measure the weight of the transported rock at speeds of up to 5 m/sec. This contradiction can be resolved only by applying new physical principles when creating measuring devices.

As the results of studies [2–11] show, when different types of electric motors are operating under load, torque oscillations occur at the nominal speed. The use of this pattern allows the weighing of the cargo on the belt conveyor by the dynamic method.

2. The study of the dynamic method of controlling the weight of cargo transported by a belt conveyor
Figure 1 shows the implementation of the proposed dynamic method for controlling the weight of cargo
transported by the conveyor.

Implemented the proposed method of controlling the weight of cargo transported by the conveyor, as follows.

Assuming that the electric motor of the conveyor 1 through the reducer 3 and the driving drum 4 must communicate the conveyor belt 5 with the mechanical energy necessary for its movement, the movement of the tension drum 6, the roller bearings 7 and the movement of the cargo 9, it is necessary to determine the moment of inertia of the rotating and moving weights, reduced to the axis of rotation of the motor shaft of the conveyor 1.

Figure 1. Dynamic method of controlling the weight of cargo transported by the conveyor: 1 – Conveyor electric motor; 2 – Position sensor, 3 – Reducer; 4 – Drive drum; 5 – Conveyor belt; 6 – Tension drum; 7 – Tensioning device; 8 – Roller bearings; 9 – Transported cargo.

According to [12], the reduced moment of inertia of the system of rotating weights is the moment of inertia of the system consisting only of elements rotating with the angular velocity of the conveyor motor shaft \( \omega_{motor} \), but having a kinetic energy reserve equal to the kinetic energy reserve of a real system. From the condition that the kinetic energy remains unchanged, it follows that for a system consisting of a drive drum 4 and a tension drum 6 connected with a reducer and rotating with angular speed \( \omega_{drum} \), having a total moment of inertia \( J_{\Sigma drum} \), the speed of movement of the conveyor belt 5, disregarding the slip, slack and thickness of the conveyor belt 5 \( V_{belt} = \omega_{drum} r_{drum} \) a little moment of inertia roller bearings.

\[
J(\omega) \frac{\omega_{motor}^2}{2} = J_{e.motor} k_{los.m.}(\omega) \frac{\omega_{motor}^2}{2} + J_{red} k_{los.red}(\omega) \frac{\omega_{motor}^2}{2} + J_{\Sigma drum} k_{los.drum}(\omega) \frac{\omega_{drum}^2}{2} +
\]

\[+(m_{belt} + m_{cargo}) \frac{V_{belt}^2}{2},
\]

where \( J(\omega) \) – reduced to the axis of rotation of the motor shaft of the conveyor 1 the moment of inertia of the reducer at the angular velocity of the shaft of the motor of the conveyor \( \omega \); \( J_{e.motor} \) – reduced to
The moment of inertia of the part of the conveyor belt rotating around the drum sectors is not taken into account in the first approximation.

From here the required reduced moment of inertia of the system is

\[
J(\omega) = J_{\text{motor}}k_{\text{los.m.}}(\omega) + J_{\text{red}}k_{\text{los.red.}}(\omega) + J_{\Sigma\text{loss}}k_{\text{los.drum}}(\omega) \left( \frac{\omega_{\text{drum}}}{\omega_{\text{motor}}} \right)^2 + \frac{(m_{\text{belt}} + m_{\text{cargo}})V_{\text{belt}}^2}{\omega_{\text{motor}}^2}.
\]  

(2)

The gear ratio between the electric motor of the conveyor 1 and the drive drum 4 is equal to the gear ratio of the reducer \(k_{\text{red.}}\).

Then (2) can be represented as

\[
J(\omega) = J_{\text{motor}}k_{\text{los.m.}}(\omega) + J_{\text{red}}k_{\text{los.red.}}(\omega) + J_{\Sigma\text{loss}}k_{\text{los.drum}}(\omega) \frac{1}{k_{\text{red.}}^2} + \frac{(m_{\text{belt}} + m_{\text{cargo}})V_{\text{belt}}^2}{\omega_{\text{motor}}^2} = \frac{J_{\text{motor}}k_{\text{los.m.}}(\omega) + J_{\text{red}}k_{\text{los.red.}}(\omega) + \left( J_{\Sigma\text{loss}}k_{\text{los.drum}}(\omega) + (m_{\text{belt}} + m_{\text{cargo}})r_{\text{drum}}^2 \right)}{k_{\text{red.}}^2},
\]

(3)

where \(r_{\text{drum}}\) – the radius of the drive drum 4 and the radius of the tension drum 6.

Torque developed by the shaft of the electric motor of the conveyor 1 when starting the conveyor without cargo \(g\) at the angular velocity of the shaft of the electric motor of the conveyor 1 \(\omega\):

\[
M(\omega) = \left[ J_{\text{motor}}k_{\text{los.m.}}(\omega) + J_{\text{red}}k_{\text{los.red.}}(\omega) + \left( J_{\Sigma\text{loss}}k_{\text{los.drum}}(\omega) + (m_{\text{belt}} + m_{\text{cargo}})r_{\text{drum}}^2 \right) \right] \varepsilon(\omega),
\]

(4)

\[
M(\omega) = \left[ J_{\text{motor}}k_{\text{los.m.}}(\omega) + J_{\text{red}}k_{\text{los.red.}}(\omega) + \left( J_{\Sigma\text{loss}}k_{\text{los.drum}}(\omega) + \frac{(m_{\text{belt}} + m_{\text{cargo}})r_{\text{drum}}^2}{k_{\text{red.}}^2} \right) \right] \varepsilon(\omega),
\]

(5)
where $\varepsilon_1(\omega)$ – angular acceleration of the motor shaft of the conveyor 1 when starting the conveyor without cargo 9.

The calculated torque equation during acceleration of the conveyor with a cargo of 9 with the angular velocity of the shaft of the conveyor motor $\omega$:

$$M(\omega) = \left[ J_{e.moto} k_{los.m}(\omega) + J_{red} k_{los_red}(\omega) + \left( \frac{J_{e.dum} k_{los.dum}(\omega) + (m_{belt} + m_{cargo}) r_{dum}^2}{k_{red}^2} \right) \right] \varepsilon_1(\omega),$$  \hspace{1cm}(6)

where $\varepsilon_2(\omega)$ – angular acceleration of the motor shaft of the conveyor 1 when starting the conveyor with a cargo of 9.

Equating (5) and (6), we determine the weight of the cargo $m_{cargo}$ transported by the conveyor:

$$m_{cargo} = \frac{k_{red}^2}{r_{dum}^2} \left( J_{e.moto} k_{los.m}(\omega) + J_{red} k_{los_red}(\omega) + \left( \frac{J_{e.dum} k_{los.dum}(\omega) + (m_{belt} + m_{cargo}) r_{dum}^2}{k_{red}^2} \right) \right) \left( \frac{\varepsilon_1(\omega) - \varepsilon_2(\omega)}{\varepsilon_2(\omega)} \right) \hspace{1cm}(7)$$

The proposed dynamic method of controlling the weight of the cargo transported by the conveyor filed an application for the invention.

The dynamic method of controlling the weight of the cargo transported by the conveyor can also be carried out on the basis of an analysis of the dynamics of the moving weight of the conveyor (belt and cargo) when the frequency of the voltage supplying the driving motor is changed for cases of movement of an empty conveyor and movement of a conveyor with some cargo (figure 2).

Figure 2. Dynamic method of controlling the cargo transported by the conveyor: 1 – Conveyor electric motor; 2 – Conveyor belt; 3 – Transported cargo; 4 – Sensor linear acceleration of the conveyor belt.

Implemented the proposed dynamic method of controlling the weight of the cargo transported by the conveyor as follows.

At the initial stage, there is no cargo on the conveyor belt. The conveyor belt with a specific law of change in the frequency of the supply voltage of the driving motor of the voltage conveyor with a certain
initial frequency in a given interval of angular velocities of the rotor of the driving motor reports acceleration $a$.

Then the frequency of the supply voltage is returned to the initial one, the cargo is placed on the conveyor belt and the frequency of the supply voltage is changed according to the same specific law of change in the frequency of the supply voltage of the driving motor, while the acceleration $a_1$ is reported to the conveyor belt with cargo.

Let's write the projections of the acting forces on the axis Ox for the first and second changes of the voltage supplying the driving motor:

$$ F = ma, $$

$$ F = (m_{belt} + m_{cargo})a_1, $$

where $m_{belt} -$ weight of conveyor belt; $m_{cargo} -$ weight of cargo.

Since the law of changing the frequency of the supply network during the first and second changes was identical, the force applied by the side of the drive motor developed with the first and second changes in the frequency of the supply network is the same.

Equating (8) to (9), we determine the unknown weight $m_{cargo}$:

$$ m_{cargo} = m_{belt} \frac{(a - a_1)}{a_1} $$

An application for the invention of the Russian Federation has been submitted for the presented dynamic method of control of the weight cargo of the transported by the conveyor based on the analysis of linear accelerations of the conveyor belt [13].

3. Conclusion
From a scientific point of view, of interest is the study of the dependence of the influence of individual internal and external factors on the accuracy of control of the weight cargo of a transported by the conveyor, the development of a control method using a dynamic method, the development of a dynamic control tool, and proposals for integrating algorithms for implementing a dynamic method into standard conveyor control systems.

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