

Simulation of load traffic and steeped speed control of conveyor

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Abstract. The article examines the possibilities of the step control simulation of conveyor speed within Mathcad, Simulink, Stateflow software. To check the efficiency of the control algorithms and to more accurately determine the characteristics of the control system, it is necessary to simulate the process of speed control with real values of traffic for a work shift or for a day. For evaluating the belt workload and absence of spillage it is necessary to use empirical values of load flow in a shorter period of time. The analytical formulas for optimal speed step values were received using empirical values of load. The simulation checks acceptability of an algorithm, determines optimal parameters of regulation corresponding to load flow characteristics. The average speed and the number of speed switching during simulation are admitted as criteria of regulation efficiency. The simulation example within Mathcad software is implemented. The average conveyor speed decreases essentially by two-step and three-step control. A further increase in the number of regulatory steps decreases average speed insignificantly but considerably increases the intensity of the speed switching. Incremental algorithm of speed regulation uses different number of stages for growing and reducing load traffic. This algorithm allows smooth control of the conveyor speed changes with monotonic variation of the load flow. The load flow oscillation leads to an unjustified increase or decrease of speed. Work results can be applied at the design of belt conveyors with adjustable drives.

1. Introduction

When designing conveyors of mining enterprises one must take into account that the incoming to a conveyor load flow varies over time. An appropriately designed drive system of a conveyor system is essential to achieve economical efficiency.

Characteristics of load flows incoming to conveyors of mining enterprises were measured by employees of Mining Institute named after A.A.Skochinskiy and other organizations. According to the results of the empirical data statistical processing, methods for calculating the optimal parameters of conveyors and hoppers have been developed. These methods ensure minimal maintenance costs. It is pointed out in [1] that due to irregular work of extraction equipment, the local conveyors work with part load most of the time. Therefore it is offered to choose the local conveyor taking into account the machine time factor of equipment and the load flow irregularity coefficient.

The search [2] showed that the load flow of the mined bulk during intensive extraction of coal in two clearing faces and one preparatory face is characterized by high non-uniformity; the coefficient of variation is 0.52. It largely determines the type and the uneven weight distribution of the load along



the belt with the coefficient of variation 0.48 at an unregulated speed of the conveyor. The uneven load flow occurs due to the technological cycle of coal extraction in the clearing and preparatory faces, the direction and speed of the movement of combined machines. The main variances of the load flow (75 %) and the weight of the transported load (85 %) coincide with low frequencies, which correspond to the periods of 2 h 8 min and 1 h 3 min and depend on the technologies of extracting and transporting the mined bulk. The minimum value of energy consumption for transporting a load by a belt conveyor corresponds to its work at full loading of the belt along the length and depending on its receiving capacity; it is 0.34 (kW·h)/(t·km).

The equalizing tension mechanisms are used in belt conveyors with variable load. The analysis of the force interaction and displacement of the drive elements and the equalizing tension device (ETD) shows that the change in the traction force of the drive with ETD is due to the change in the tension of the belt [3].

When the belt speed, for example, equals 2 m/s, there is 120 m length of the loaded conveyor belt for one minute. So, for evaluating the belt workload and absence of spillage there is a need to use empirical values of load flow in a shorter period of time. Characteristics of a minute load are suitable for calculation of a conveyor with a hopper equipped with a feeder. There is a need of values Q_c for $t_Q = 1...3$ seconds to analyze load of conveyors without hoppers. Processing of the measurements of the coal mine faces' load flows has shown that the coefficient of variation of Q_c reaches at 0.73 when $t_Q = 1.2$ s [4].

2. Possibilities of the conveyor speed control

An important way to reduce operational costs is to control the speed of the conveyor according to the actual load. Regulation conveyor speed did not receive previously widespread in mining enterprises due to lack of reliable and efficient control equipment.

Multi-speed asynchronous motors allow discretely changing the speed of the conveyor. Their use provides the belt movement with multiple constant speeds, but adjustment the motor speed to desired speed of the conveyor is almost impossible. In addition, the gear change is accompanied by harmful electromagnetic and mechanical processes in the conveyor drive. New opportunities of regulation emerged with the creation of semiconductor electric control devices that allow you to adjust a wide range of speed and electromagnetic torque of an asynchronous motor.

The incoming to a conveyor load flow varies almost continuously. If the control unit also changes the conveyor speed continuously in accordance with Q_c , the conveyor constantly works in transient dynamic mode with increased wear and energy consumption. Stepped speed control reduces the amount and time of transient dynamic processes, enhances conveyor performance by providing full load of the belt without spillages and reducing energy losses and wear of the conveyor units [5].

To select the optimal number of steps and the corresponding velocity values, one can use the power consumption of the conveyor or the reduced cost of transportation as criteria. However, it is impossible to calculate these figures with reasonable accuracy. It is better to use speed average value or the path, traversed by the belt for a set time, as the efficiency criterion of the conveyor speed regulation.

The dependences for calculating steps of speed V_i for stationary normal random process Q_c were shown in [6]. However, many researchers have noted that most of the load flows are neither stationary nor normal random processes [7]. Therefore, formulas [6] can only be used for a rough estimation of the values V_i . To evaluate the values V_i more precisely, it is necessary to have speed regulation process modeling with the real values Q_c for a shift or a day.

The calculated value of the average speed m_V depends on the expected relative duration P_i of the conveyor with the speed of the i -th stage:

$$m_V = \sum_{i=1}^S V_i P_i, \quad \sum_{i=1}^S P_i = 1. \quad (1)$$

S is the number of control steps.

The P_i values can be calculated through the statistical estimation $p(x)$ of the total load flow duration $Q_c = x$ for the observation period, i.e. through the statistical density of the Q_c distribution:

$$P_i = \int_{Q_{i-1}}^{Q_i} p(x) dx, \quad i = 1, \dots, S.$$

The speed of the i -th stage V_i is expressed in terms of the nominal running load ψ and the value of the load flow Q_i corresponding to the i -th stage ($V_i = Q_i/\psi$). The value of the nominal running load ψ is a constructive characteristic of the conveyor and ensures its normal operation without spilling the load ($\psi = Q_n/V_n$). Q_n and V_n are nominal values of productivity and conveyor speed.

The necessary condition for a minimum of the average speed m_V is

$$\frac{dm_V}{dQ_i} = 0, \quad i = 1, \dots, S-1. \quad (2)$$

3. Simulation within Mathcad

The purpose of the simulation of the conveyor speed control process is the test of the algorithm availability and determination the optimal control parameters corresponding to the characteristics of the incoming flow Q_c . For example, determining the optimal number of control steps and corresponding values of productivity.

The average speed m_V and the number of speed switching N_n in the simulation period should be used as the criteria of the regulation efficiency.

Initial data for the simulation are empirical measurement of load Q_c . Only single 8-hour shift measurement results include 28,800 Q_c values with $t_Q = 1$ sec.

The processing of large data sets is possible within mathematical programs Mathcad and Matlab, or programs specifically written for this task in one of the programming languages.

Let us consider the example of a conveyor speed control process simulation using Mathcad program. The initial data used 104 Q_c values with expected value of 29.1 kg/s and a standard deviation of 14.2 kg/s. $t_Q = 3$ c. The maximum values of Q_c are 50 kg/s, which corresponds to the theoretical capacity of the conveyor 180 t/h. $t_Q = 3$ s.

The values of m_V and N_n for two-step, three-step and four-step control regimes were calculated with linear interpolation of 104 load data and the use of Mathcad programming operators for nominal speed value $V_n = 2.5$ m/s.

The calculated values of m_V and N_n for optimal rates of speed stages V_i/V_n ($i = 0 \dots S$) are put in the table. Optimal values V_i were calculated with using formulas (1), (2).

The number of speed ratios V_i/V_n in the table exceed S by 1 because it was accepted that $V_0 = V_n/8$ if $Q_c = 0$. Additional V_0 step allows low creep speed to facilitate inspection.

Table 1. Results of Simulation.

S	V_i/V_n	m_V , m/s	N_n
2	0.125; 0.66; 1	1.96	11
3	0.125; 0.3; 0.66; 1	1.79	16
4	0.125; 0.25; 0.6; 0.75, 1	1.74	24

The graph in figure 1 shows how the load flow Q_c and speed of the conveyor are changed by time. Q_c values are multiplied by 0.05 for equalizing the scale with speed values. V_{two} , V_{three} , V_{four} – conveyor speed for two-step, three-step and four-step control modes.

For the initial data of the example, the average speed m_V decreases significantly at two-step or three-step control. Four-step mode decreases m_V by 2.9 % only compared with three-step mode, but increases N_n essentially by 53 %. A further increase in the number of regulatory steps decreases average speed insignificantly but considerably increases the intensity of the speed switching.

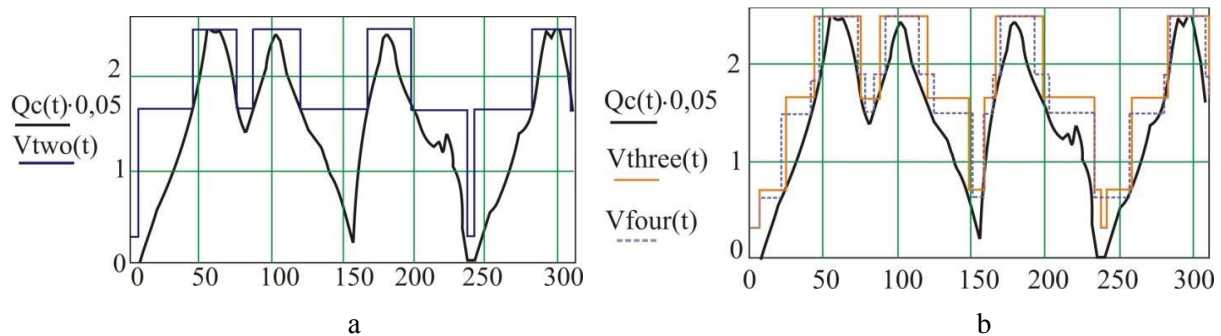


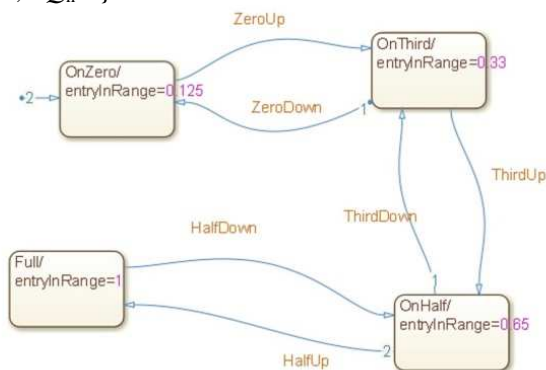
Figure 1. Changes of the load flow Q_c and speed of the conveyor V (m/s) by time: a – two-step regulation, b – three-step and four-step regulation

4. Simulation within Simulink/Stateflow

Simulation within Simulink/Stateflow extension of Matlab program has a greater opportunity to test complex conveyor speed control algorithms in comparison with the Mathcad software.

The developed model of the event-controlled system for the stepwise control of the conveyor speed within Simulink/Stateflow software includes the “Read from File” block, the “Scope” block, the “HitCrossing” blocks and the Chart diagram. Stateflow chart runs as a block in a Simulink model.

Six blocks 'HitCrossing' correspond to three steps of increasing Q_c and three steps of decreasing Q_c . The parameters of the “HitCrossing” blocks are set so that the step change takes place, if $Q_c = \{0, Q_n/3, 2Q_n/3\}$ with an increase and decrease of traffic.



Additional block “HitCrossing” monitors exceeded the maximum allowable traffic $Q_c > Q_{\max}$ ($Q_{\max} \approx 1.05Q_n$) and sent a signal to stop the download.

Chart contains four states (figure 2) corresponding to the velocity values of stages $V_i = \{V_0, V_I, V_2, V_n\}$. The model reacts to events by changing states.

Figure 2. The scheme of transitions between four states of Stateflow chart

To operate the Chart, its input port gets the signals of the “HitCrossing” blocks combined into the vector signal. The order of the vector input signal elements corresponds to the order of events [8]. Events determine the time of the model state changes. For instance, the event «CrossQ0Up» matches up the moment of appearance load value $Q_c > 0$ and determines the belt speed transition from V_0 value to V_I .

The graphs of the load flow Q_c and speed of the conveyor V (m/s) calculated within Simulink/Stateflow software coincident with the above Mathcad simulation results.

5. Incremental algorithm of conveyor speed control

In the considered example, the V_i values of the speed steps remain constant, but in [9] a method is proposed for stepwise control of the conveyor belt speed in which the number of control steps and the speed of the steps take different values as the load flow increases and decreases. The method includes continuously measuring the actual speed V of the belt at the loading point and incoming load flow Q_c , changing the speed of the belt by controlling the drive of the conveyor. The receiving capacity of the conveyor q_{out} (kg/s) depends on the current speed V of the belt at the loading point and the nominal running load ψ (kg/m) of the conveyor ($q_{\text{out}} = \psi V$).

According to the method, the belt speed V is increased by the value q_I/ψ at time Δt_I if the incoming

load flow Q_c exceeds the conveyor receiving capacity q_{out} ; or V is decreased by q_2/ψ at time Δt_2 if Q_c is less than q_{out} by the value q_2 . Otherwise, the belt speed V remains unchanged if Q_c is in the range of values from $q_{out} - q_2$ to q_{out} , or the conveyor loading is stopped without changing V if Q_c exceeds the conveyor maximum capacity Q_{max} .

Here, q_1 & q_2 are the ratios of the nominal capacity of the conveyor Q_n to the selected number of control stages N_1 and N_2 with increasing and decreasing belt speed. The time intervals Δt_1 and Δt_2 are necessary for a smooth change of speed V . If a_1 and a_2 are permissible acceleration and deceleration of the belt, then $\Delta t_1 \geq q_1/\psi a_1$, $\Delta t_2 \geq q_2/\psi a_2$.

The simulation model of the incremental algorithm of conveyor speed control [9] was developed within Simulink software using the blocks “Read from File”, “Scope”, “HitCrossing”, “Unit Delay”, “Saturation” for the three-stage mode of speed increasing and the two-stage mode of speed reducing (figure 3). The three-stage mode increases the speed V of the belt from the initial value V_0 to nominal value V_n . The two-stage mode reduces the speed V of the belt from the nominal value V_n to V_0 . In these cases, $q_1 = Q_n/3$, and $q_2 = Q_n/2$. The parameters of the “HitCrossing” blocks are set so that the step changeover takes place if $Q_c = \{0, Q_n/3, 2Q_n/3\}$ with increasing traffic and $Q_c = \{Q_n/2, 0\}$ with a decrease of traffic. The additional block “HitCrossing” controls the excess of $Q_c > Q_{max}$ and signals the termination of the load.

The simulation results for the same 104 values of load flow Q_c are presented in figure 3.

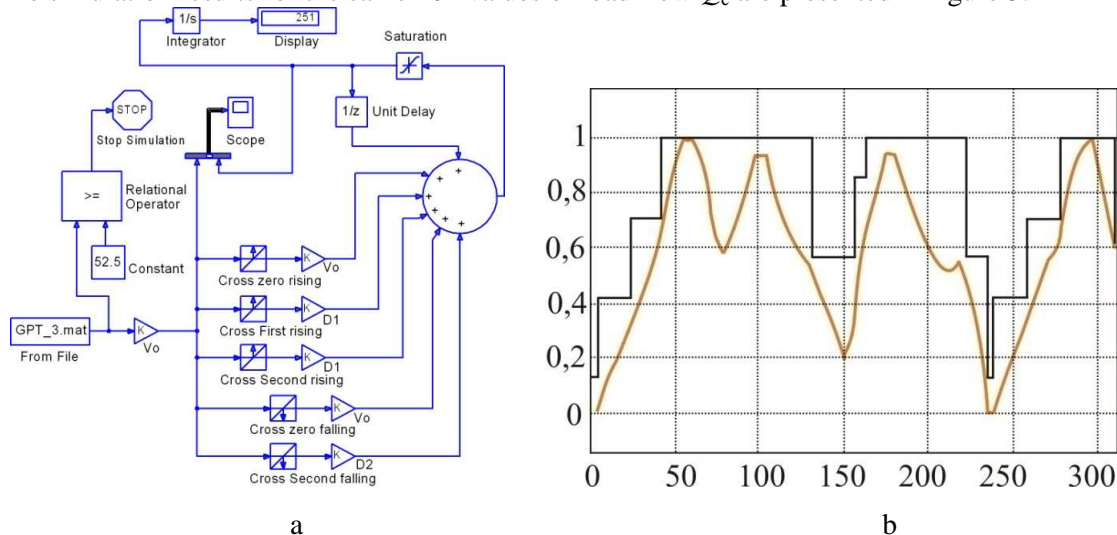


Figure 3. The model scheme (a) and the graph (b) of the load flow Q_c and speed of the belt V (m/s) calculated within Simulink software. The scale along the abscissa for t is 1: 1 s; the scale along the ordinate axis for Q_c is 1:50 kg/s, for V - 1: 2.5 m/s

The three-stage mode allows one to increase the belt speed V by the value $\Delta_1 = (V_n - V_0)/3$. The two-stage mode allows one to reduce the belt speed V by the value $\Delta_2 = (V_n - V_0)/2$. A greater number of stages with increasing speed and less with a decrease allows a smooth increase in speed and reduce the number of speed switching with a decrease of load traffic.

Reduction of the number of control stages with a decrease in load flow allowed one to reduce the number of speed switching to 12 and slightly increased m_v to 2.03 m/s in comparison with the fully three-step regime (figure 1b). So, the number of speed switching decreased 1.54 times, the average speed m_v increased by 12.8% (see the table).

Simulation of the incremental algorithm showed the possibility of controlling the smoothness of the change in conveyor speed with a monotonic change of the load flow Q_c . However, oscillations of the Q_c value near the step values Q_i lead to unreasonable overstating or understating of the conveyor speed.

The considered approaches to simulation within three different software types are applicable not for conveyors only, but also for excavator-car complexes of quarries [10]. The simulation approaches allow evaluating the effectiveness of the dispatch algorithm, to determine the ways to increase the performance of transport complexes of quarries.

6. Conclusion

Wherever energy savings, availability, reliability, reduced equipment wear are an issue, speed controlled belt conveyor drive systems are the most economical drive option for belt conveyors. The step mode speed control allows higher speed applications, reduced overall energy consumption and higher efficiency of conveying systems.

Probabilistic methods of estimating the conveyor loading and speed regulating do not allow obtaining results with sufficient accuracy because of difficulty of formal description of load flows at mining enterprises. To check the efficiency of the control algorithms and to more accurately determine the characteristics of the control system, it is necessary to simulate the process of speed control with real values of traffic for a work shift or for a day.

For evaluating the belt workload and absence of spillage there is a need to use empirical values of load flow in a short period of time (1...3 sec.) to analyze load of conveyors without hoppers.

Simulation within Mathcad, Simulink, Stateflow software allows one to find the control system characteristics with acceptable tolerance and expenses. Two-step and three-step control modes decrease the conveyor average speed m_v essentially. A further increase in the number of regulation steps decreases average speed m_v insignificantly.

Simulation of the incremental algorithm showed the possibility of controlling the smoothness of the change in conveyor speed with a monotonic change of the load flow Q_c . However, oscillations of the Q_c value near the step values lead to unreasonable overstating or understating of the conveyor speed.

The considered approaches to simulation within three different software types are applicable for different transport complexes of quarries and mines. The simulation approaches allow evaluating the effectiveness of the dispatch algorithm, determining the ways to increase the performance of transport complexes.

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