MOTROL, 2012, 14 - №3, 120-125

УДК 621.87

OPTIMIZATION OF START-UP MODE OF THE SCRAPER CONVEYOR

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Summary. The paper is devoted to optimization technique of start-up mode of scraper conveyor. The criterion, which is selected to estimate the motion mode of the conveyor, is the root-mean-square deviation of accelerations of conveyor chain and the masses' center of scrapers with chain and cargo. The optimum motion mode of system and the law of change of the driving moment, which leads dynamic loadings to minimum, is received.

Key words: scraper conveyor, mathematical model, dynamic loadings, optimum motion mode, differential equation of motion.

1. INTRODUCTION

By the previous theoretical researches [8, 9] we have defined that in the chain of the scraper conveyor arose oscillatory processes with considerable change of velocity and acceleration during start-up. Such processes have been caused by dynamic loadings in conveyor chain and drive elements. All these lead to the premature destruction and decreases reliability of conveyor work.

In order to solve such problem it is necessary to minimize dynamic loadings by means of choosing optimum law of motion of the scraper conveyor during start-up.

To optimize the traffic controls often use variational calculus, which gives the chance to obtain smooth operating functions. It allows to "soften" motion mode of system.

2. MATERIAL AND METHODS

Work [10] is devoted to research the optimization of motion modes of different mechanical systems.

In paper [12] technique for solving optimization problems of motion of mechanical systems, using direct variation method, is described. The authors have minimized the root-mean-square value of dynamic component of driving forces of the mechanical system.

In work [11] the way for elimination the fluctuations of cargo during start-up of the crane crab is considered. As optimization criterion of the transitive mode is accepted quadratic difference of velocity of the crane crab and cargo.

Works [7, 15, 16] deal with mathematical models construction and research of dynamic processes, which arise in conveyors with chain.

Research [7] is devoted to mathematical model for definition loadings in driving mechanism and chain of the scraper conveyor with two-high-speed asynchronous electric motors on example of coal transportation.

However investigation of optimization motion modes of scraper conveyors for transportation of agricultural cargoes practically weren't carried out.

Therefore the research objective is the optimization start-up mode of the scraper conveyor for minimization of dynamic loadings which arise in chain and drive elements of the conveyor.

3. RESULTS AND DISCUSSION

Optimization of start-up process is carried out with use of four-mass dynamic model of the scraper conveyor (fig. 1). Non-working branch of the conveyor is not taken into account, because from the previous researches we have established that its influence on motion character is insignificant.

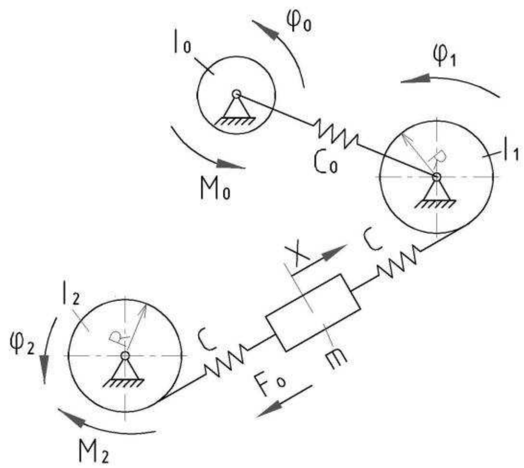

Fig. 1. Dynamic model of the scraper conveyor.

Constructing mathematical model, we have made such assumptions:

- all elements of the scraper conveyor are absolutely hard bodies, except elements of the transfer mechanism and chain, which have elastic properties.

- body of driving mechanism of the conveyor and shafts' bearings of traction sprocket and tension sprocket are fixed absolutely rigidly.

The set of the differential equations, which describes dynamic processes in the scraper conveyor, is made on the basis of the accepted dynamic model with use of d'Alembert's principle and looks so:

$$\begin{cases} I_0\ddot{\varphi}_0 = M_0 - c_0\left(\varphi_0 - \varphi_1\right); \\ I_1\ddot{\varphi}_1 = c_0\left(\varphi_0 - \varphi_1\right) - cR\left(\varphi_1 R - x\right); \\ m\ddot{x} = c\left(\varphi_1 R - x\right) - c\left(x - \varphi_2 R\right) - F_o; \\ I_2\ddot{\varphi}_2 = cR\left(x - \varphi_2 R\right) - M_2, \end{cases} \tag{1}$$

where

I_0 - the inertia moment of elements of the driving mechanism, which are erected to an axis of the power shaft;

I_1, I_2 - the inertia moments of driving shaft and tension shaft of the conveyor concerning own axes of rotation;

$\varphi_0, \varphi_1, \varphi_2$ - angular coordinates of turn respectively of driving mechanism, driving sprocket and tension sprocket of the conveyor;

x - linear coordinate of masses' center of the working branch of the conveyor;

m - mass, which is concentrated on the working branch of the conveyor;

c_0 - stiffness coefficient of driving mechanism, which is erected to the turning axis of the power shaft;

c - stiffness coefficient of the traction chain of the conveyor;

R - radiuses of driving sprocket and tension sprocket;

M_0 - the start-up torque on motor shaft, which is erected to the turning axis of the power shaft;

M_2 - moment of resistance arising from scooping cargo by scrapers, which is erected to the turning axis of the tension shaft.

F_o - resistance force from the moving of the working branch of the conveyor.

From the equations of system (1) we have found linear coordinate of the centre of masses of conveyor's working branch x, angular coordinates of turn of driving mechanism φ_0, driving drum φ_1, and also the start-up torque M_0, using angular coordinate φ_2 and its derivatives. Herewith the driving moment looks like:

$$\begin{aligned} M_0 = {} & \left(mR^2 + I_0 + I_1 + I_2\right)\ddot{\varphi}_2 + \left\{ \frac{I_0}{c_0}\left[\frac{c_0}{c}\left(m + \frac{2I_2}{R^2}\right) + mR^2 + I_1 + I_2\right] + \right. \\ & \left. + \frac{m}{c}\left[I_1\left(1 + \frac{2I_2}{mR^2}\right) + I_2\right]\right\}\overset{IV}{\varphi_2} + \frac{mI_0I_1I_2}{c_0 c}\overset{VIII}{\varphi_2} + M_2 + F_o R. \end{aligned} \tag{2}$$

Integral functionals are used as criteria to estimate the motion modes of machines. They depend on motion modes of mechanisms. Functionals display dynamics of machines taking into account constructed mathematical model [12]. As these criteria display undesirable properties of mechanisms, that's why they should be minimized.

Estimation criterion of motion mode of the scraper conveyor during start-up is the root-mean-square deviation of accelerations of chain during the moment of running on driving drum and the center of masses of scrapers with chain and cargo. Taking into account the equation of system (1), criterion looks like:

$$I_{12} = \left[\frac{1}{t_1} \int_0^{t_1} f_{12} dt \right]^{1/2}; \qquad (3)$$

where t_1 - time of acceleration of the conveyor.

$$f_{12} = (\ddot{\varphi}_1 R - \ddot{x})^2 = \left(\frac{1}{c}\left(mR^2 + I_2\right)\overset{IV}{\varphi}_2 + \frac{mI_2}{c^2}\overset{VI}{\varphi}_2 \right)^2, \qquad (4)$$

Euler-Puasson's equation [2] is minimum criterion condition (3) with subintegral expression (4):

$$\frac{\partial f_{12}}{\partial \varphi_2} - \frac{d}{dt}\frac{\partial f_{12}}{\partial \dot{\varphi}_2} + \frac{d^2}{dt^2}\frac{\partial f_{12}}{\partial \ddot{\varphi}_2} - \frac{d^3}{dt^3}\frac{\partial f_{12}}{\partial \dddot{\varphi}_2} + \frac{d^4}{dt^4}\frac{\partial f_{12}}{\partial \overset{IV}{\varphi}_2} - \frac{d^5}{dt^5}\frac{\partial f_{12}}{\partial \overset{V}{\varphi}_2} + \frac{d^6}{dt^6}\frac{\partial f_{12}}{\partial \overset{VI}{\varphi}_2} = 0. \qquad (5)$$

As function f_{12} depends from $\overset{IV}{\varphi}_2$, $\overset{VI}{\varphi}_2$, thus equation (5) becomes:

$$\frac{\partial f_{12}}{\partial \varphi_2} = \frac{\partial f_{12}}{\partial \dot{\varphi}_2} = \frac{\partial f_{12}}{\partial \ddot{\varphi}_2} = \frac{\partial f_{12}}{\partial \overset{V}{\varphi}_2} = 0,$$

$$\frac{d^4}{dt^4}\frac{\partial f_{12}}{\partial \overset{IV}{\varphi}_2} + \frac{d^6}{dt^6}\frac{\partial f_{12}}{\partial \overset{VI}{\varphi}_2} = \left(\frac{1}{c}\left(mR^2 + I_2\right)\overset{IV}{\varphi}_2 + \frac{mI_2}{c^2}\overset{VI}{\varphi}_2 \right)^2 = 0. \qquad (6)$$

In order to simplify the solution are accepted such designations:

$$\frac{1}{c}\left(mR^2 + I_2\right) = a, \quad \frac{mI_2}{c^2} = b$$

Having defined partial derivatives and time derivatives for the equation (6), we have obtained:

$$a\overset{VIII}{\varphi}_2 + 2ab\overset{X}{\varphi}_2 + 2b\overset{XII}{\varphi}_2 = 0. \qquad (7)$$

We have defined the general solution of the equation (7). For this purpose we have found roots of the characteristic equation. Considering that $\varphi_2 = e^{\lambda t}$, we have written down the equation (7) so:

$$e^{\lambda t}\left(a\lambda^8 + 2ab\lambda^{10} + 2b\lambda^{12}\right) = 0.$$

where λ - the root of the characteristic equation.

As $e^{\lambda t} > 0$, so $a\lambda^8 + 2ab\lambda^{10} + 2b\lambda^{12} = 0.$

As a result of the executed calculations for the conveyor with parameters $m = 76kg;\ I_2 = 0{,}00171 kg \cdot m^2;\ R = 0{,}0535 m;\ c = 1{,}3 N/m$, we have found the roots of the characteristic equation:

$$\begin{aligned} &\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = \lambda_6 = \lambda_7 = \lambda_8 = 0, \\ &\lambda_9 = -27{,}21 - 27{,}21i, \\ &\lambda_{10} = -27{,}21 + 27{,}21i, \\ &\lambda_{11} = 27{,}21 - 27{,}21i, \\ &\lambda_{12} = 27{,}21 + 27{,}21i. \end{aligned} \qquad (8)$$

As we have eightfold-degenerate and complex roots of the characteristic equation (8) the solution of the differential equation (7) looks like:

$$\begin{aligned} \varphi_2(t) = {} & C_1 + C_2 t + C_3 t^2 + C_4 t^3 + C_5 t^4 + C_6 t^5 + C_7 t^6 + C_8 t^7 + C_9 e^{-27{,}21t}\sin(27{,}21t) + \\ & + C_{10} e^{-27{,}21t}\cos(27{,}21t) + C_{11} e^{27{,}21t}\sin(27{,}21t) + C_{12} e^{27{,}21t}\cos(27{,}21t) \end{aligned} \qquad (9)$$

where $C_1, ..., C_{12}$ - constants of integration, which are determined from the initial conditions of motion.

For definition of these constants it is necessary to set twelve boundary conditions of motion:

$$when\ t = 0 \quad \Rightarrow \quad \varphi_2 = 0,\ \dot{\varphi}_2 = 0,\ \ddot{\varphi}_2 = 0,\ \dddot{\varphi}_2 = 0,\ \overset{IV}{\varphi}_2 = 0,\ \overset{V}{\varphi}_2 = 0;$$

$$when\ t = t_1 \quad \Rightarrow \quad \dot{\varphi}_2 = \omega_y,\ \ddot{\varphi}_2 = 0,\ \dddot{\varphi}_2 = 0,\ \overset{IV}{\varphi}_2 = 0,\ \overset{V}{\varphi}_2 = 0,\ \overset{VI}{\varphi}_2 = 0,$$

where ω_y – the settling velocity of turn of a tension shaft.

Having defined integration constants, we have put them in expression (9) and have received the optimum law of motion of tension drum.

By means of this mode, using the equation of system (1), optimum motion modes of driving mechanism and driving drum of the conveyor are obtained. Change of velocity and acceleration of these links has the same character, as in tension drum.

Graphs of angular velocity (fig. 2), of angular acceleration (fig. 4) of tension shaft at optimum mode of the start-up and of the start-up torque (fig. 6) are constructed, using such parameters of dynamic model:

$$m = 76kg;\ I_0 = 0{,}7435 kg \cdot m^2;\ I_1 = I_2 = 0{,}00171 kg \cdot m^2;\ c_0 = 7378 H \cdot m/rad;$$

$$c = 1{,}3 \cdot 10^6\ N/m;\ R = 0{,}0535 m;\ M_2 = 0{,}55 N \cdot m;\ F_o = 1350 N;\ \upsilon = 1{,}5 m/s;\ t_1 = 1s.$$

To demonstrate influence of optimization of motion mode of the conveyor on character of motion of the conveyors' links, we demonstrate for comparison the graphs of change of angular velocity and acceleration during nonoptimal (valid) motion mode. Graphs are constructed, using the same parameters of the dynamic model (fig. 3, 5).

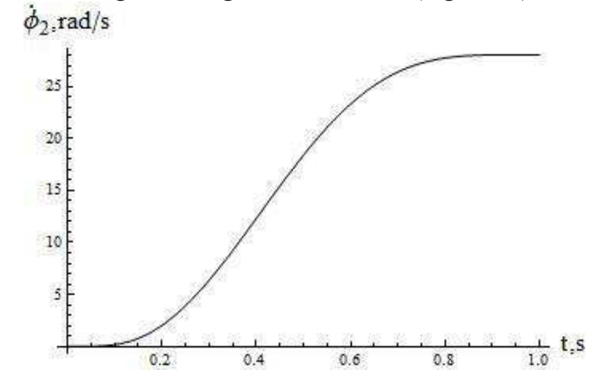

Fig. 2. The graph of change of angular velocity $\dot{\varphi}_2$.

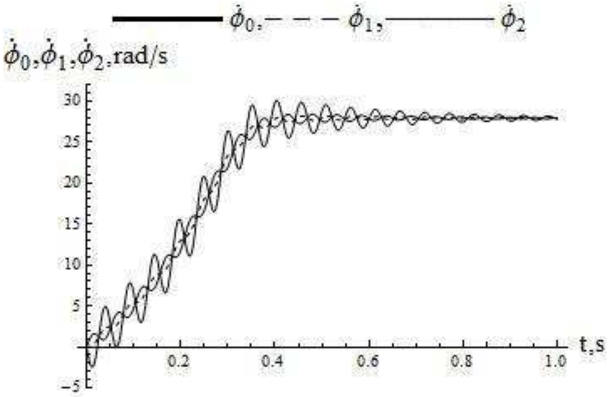

Fig. 3. The graph of change of angular velocities $\dot{\varphi}_0, \dot{\varphi}_1, \dot{\varphi}_2$ without optimization of start-up mode.

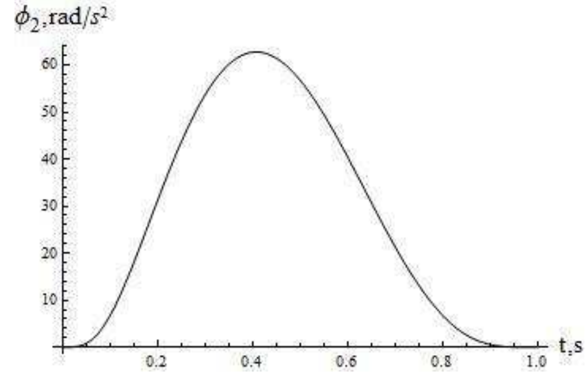

Fig. 4. The graph of change of angular acceleration $\ddot{\varphi}_2$.

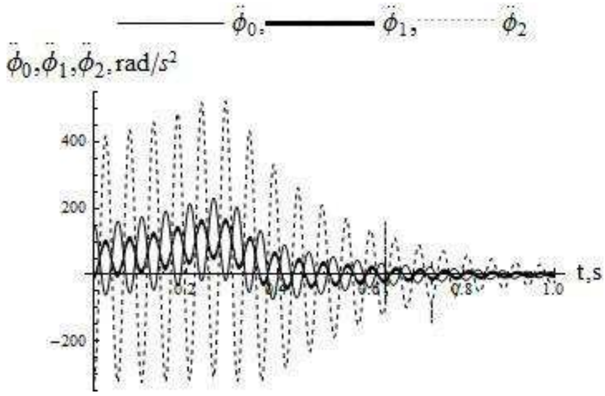

Fig. 5. The graph of change of angular accelerations $\ddot{\varphi}_0, \ddot{\varphi}_1, \ddot{\varphi}_2$ without optimization of start-up mode.

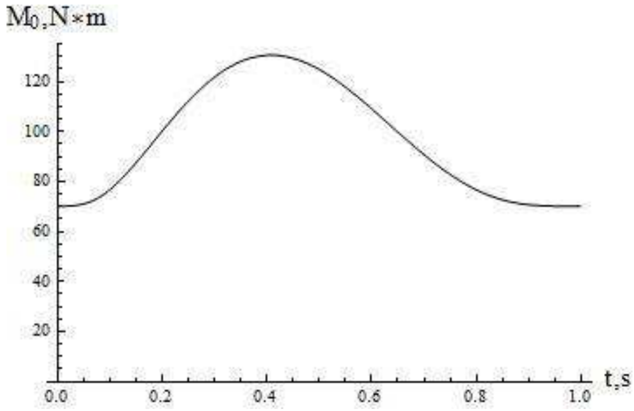

Fig. 6. The graph of change of the motive moment of a driving mechanism M_0 .

Analyzing the conducted researches and comparing optimum graphs of change of angular velocity and angular acceleration of the conveyors' links to graphs without optimization, it is possible to make conclusions that such mode of start-up has given the chance to minimize fluctuation in links of drive mechanism and flexible chain of the scraper conveyor, caused by dynamic loadings. During the valid motion mode of the conveyor the fluctuations of angular velocity were within 10 … 6 rad/s, and fluctuations of angular acceleration had very intensive character (the maximum values changed from-250 to 450 rad/s^2).

Hence, the obtained optimum mode of start-up provides smooth change of angular velocity and acceleration of the scraper conveyors' links, and also of the start-up torque on the shaft of the engine erected to the power shaft of the conveyor.

4. CONCLUSIONS

On the basis of the constructed mathematical model, the optimization of dynamics of conveyor motion on a start-up has been conducted. Criterion of optimization is the root-mean-square deviation of chain accelerations during the moment of running on driving drum and the masses' center of scrapers with chain and cargo. Putting into practice the offered technique of optimization of start-up mode of the scraper conveyor can be reduce action of dynamic loadings to minimum and, as consequence, raise productivity and reliability of work of the conveyor.

5. LITERATURE

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ОПТИМИЗАЦИЯ СПОСОБА ЗАПУСКА СКРЕБКА КОНВЕЙЕРА

Аннотация. Статья посвящена методам оптимизации способа запуска скребка конвейера. Критерий, который отобран, чтобы оценить способ движения конвейера, является среднеквадратичным отклонением ускорения цепи конвейера и центра масс скребков с цепью и грузом. Получено оптимальный способ движения системы и закон изменения ведущего момента, который приводит динамическую нагрузку к минимуму.

Ключевые слова: скребок конвейера, математическая модель, динамическая нагрузка, оптимальный способ движения, отличительное уравнение движения.