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MATHEMATICAL MODEL OF APRON CONVEYOR CONTROLLED ELECTRIC DRIVE IN OPERATION STARTING MODES

Abstract. Starting a long multi-drive apron conveyor is a difficult task, since it is accompanied by excessive loosening of the traction body. Particularly unfavorable are the conditions for starting a apron conveyor, the apron of which has slack sections, as a result of which rigidity of the working member that is a function of its tension and load on it, is relatively small. The presence of intermediate drives does not allow controlling the initial tension of the traction body. In this regard, the task of developing a method that allows smooth starting long multi-drive conveyor is urgent.

The purpose of this work is developing a mathematical model of two-drive apron conveyor with a controlled electric drive in operation starting modes, taking into account elastic properties of the traction body. The article presents a developed method of smooth starting electric drives of the apron conveyor. The proposed method of starting the apron conveyor that consists in using a frequency-controlled electric drive, allows obtaining a needed starting mode of the conveyor. The technical result of the proposed method is increasing reliability of the apron conveyors by reducing dynamic loads on the working body in starting modes and increasing the resource of the working body of the conveyors. On the basis of this method, a mathematical model has been developed, which is described by the two-mass system of differential equations. Based on the developed mathematical model of the conveyor starting method, a simulation model of the electric drive has been built in the Matlab Simulink software package.

Keywords: multi-drive apron conveyor, mathematical model, asynchronous variable-frequency electric conveyor, smooth start of electric drive, alternation of slacking and tensioning processes.

Introduction. It is known that the performance of the conveyor depends on the specific load and speed of transportation. Low speeds used in chain conveyors, usually not exceeding one meter per second, form the most unfavorable mode of operation. High linear loads, large static tensions in the chain lead to developing bulky and metal-consuming machines [1]. The speed of cargo transportation is often determined by the technological process, the conditions of loading and unloading, the design features of the conveyor, the properties of the cargo, the speed of information processing by the electronic control system. In order to improve the performance of the conveyor, there can be increased the volume of the load per unit length of the traction chain or transportation speed [2]. However, *ceteris paribus*, the speed is limited by the dynamic loads in the traction chains and other elements of the conveyor. Dynamic loads in chain conveyors arise during starting and braking and can be caused by the kinematics of the drive mechanism gearing with the traction chain, during loading and unloading.

The most important cause leading to the short service life of the chain traction body of the conveyor is fatigue life [3]. Fatigue life is mainly determined by oscillatory processes occurring in the chain in steady-state operating conditions. An effective way of reducing dynamic loads is using an automated electric drive.

It is known that the conveyor elements wear is a regular reduction of its size and occurs depending on the operating time of the mechanism or machine [4, 5]. The physical quantity "wear rate" allows finding the pattern of its change within a relatively short period of time of the mechanism operation, to calculate its service life. In this case, the wear rate of the conveyor elements is determined within the period of steady state operation. During transportation of abrasive, rocky rock mass by apron conveyors, wear traction body and trailer sprockets of the conveyor wear the worst. As noted in [6], such factors as the traction body tension increment, the ambient temperature, the surface hardness of materials, the speed of the conveyor apron movement, the linear mass of the load and mechanical strength of the abrasive particle for destruction affect the wear rate of the chain and sprockets.

Material and results of research. Starting a long apron conveyor is a difficult task [4], since it is accompanied by excessive loosening of the traction body in front (in the direction of the apron travel) of the drive.

Particularly unfavorable are the conditions for starting a apron conveyor, the apron of which has slack sections, as a result of which rigidity of the working member that is a function of its tension and load on it, is relatively small.

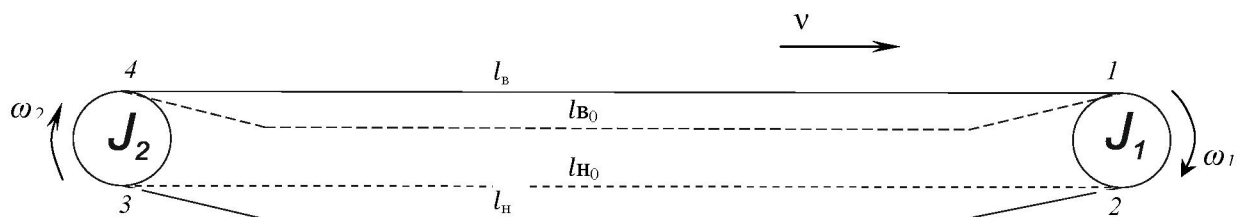


Figure 1 – The conveyor starting process diagram:

l_{B0} – the traction body carrying run length before tensioning; l_B – the traction body carrying run length after tensioning;

l_{H0} – the traction body bottom run length after tensioning; l_H – the traction body bottom run length before tensioning

Figure 1 shows a diagram of the conveyor starting process. When starting the conveyor, the head drive first turns on. Starting rotation of the traction sprocket of the head drive that will occur some time after the engine is turned on will cause occurring an elastic wave that will move along the upper apron from the head to the tail drive. To ensure trouble-free starting the conveyor, there is provided a preparation mode, according to which, before each starting, an initial tension determined by starting calculation is formed in the traction body, after which the tensioning device is rigidly fixed [9].

In case of multi-drive conveyors, solving the starting problem is even more difficult. The presence of intermediate drives does not allow controlling the initial tension of the traction body in this way. Such control is possible only when a tensioner is mounted on each drive, which is structurally feasible, but difficult. Various methods and technical solutions are used to ensure the working body tension, but they are all associated with the increasing complexity of the conveyor drive systems. An alternative option is using a variety of controlled drive systems. This allows providing the ability to implement control of starting modes with reduction of overloads in the working body due to controlling its tension.

In this regard, the task of developing a mathematical model of a controlled electric drive apron conveyor in starting modes, taking into account the elastic properties of the traction body, is urgent.

The essence of the proposed method of smooth starting a multi-engine electric drive apron conveyor, based on measuring load currents and separating their active components, as well as controlling the drives during the starting process, there is set the minimum speed of the electric drive during starting a the multi-engine electric drive of the apron conveyor, and with intensive increasing the active component of the master drive load current there is increased the rotation speed of the master and slave drives to the rated one.

Within the period of the conveyor starting, the engine has to save energy to overcome the inertia forces of the load and parts of the conveyor [10, 11], in addition to the energy of overcoming static resistances. Thus, during starting the conveyor, the electric engine should develop the moment

$$M_{\Pi} = M_c + M'_{\Pi} + M''_{\Pi}, \quad (1)$$

where M_c is the moment of overcoming static resistances of the conveyor; M'_d is the dynamic moment for overcoming the load, the working member and the rotating parts of the conveyor (without the drive) inertia forces; M''_d is the dynamic moment for overcoming the conveyor drive parts inertia forces.

To determine M_c there is firstly determined the torque moment on the drive sprocket

$$M_{\pi} = \frac{P_{cm.n.} * D_0}{2}, \quad (2)$$

where $P_{cm.n.}$ is the static traction force of the starting period; D_0 is the design diameter of the drive sprocket.

The conveyor traction force in starting is higher than when with the fixed movement due to the fact that friction resistances in rest exceed approximately 1.5 times friction resistances in movement [11].

The moment on the engine shaft for overcoming $M_{\pi p}$

$$M_c = \frac{P_0 * D_0}{2 * i_0 * \eta_0}. \quad (3)$$

The moment on the engine shaft ($H * M$) for overcoming P_d at $\vartheta = D_0 * w_{\partial} / 2i_0$

$$M'_d = \frac{P_d * D_0}{2 * i_0 * \eta_0} = \frac{G_{\partial} * w_{\partial} * D_0^2}{4 * i_0^2 * t_{\pi} * \eta_0}, \quad (4)$$

where G_{∂} is the reduced mass of the load and the moving parts of the conveyor; P_d is an additional force on the mechanism from the working member and the conveyor rotating parts load acceleration.

The dynamic moment for the conveyor rotating parts acceleration

$$M''_d = \frac{P_d * D_0}{2 * i_0 * \eta_0} = \frac{c_i (G_i * D_0)^2 * w_{\partial}}{4 * t_{\pi}}, \quad (5)$$

where $c_i = 1.1 \div 1.5$ is the coefficient accounting the gearing mechanism parts acceleration that rotate with the angular speed lower than w_{∂} ; $(G_i * D_0)^2$ is the rotative moment on the engine shaft accounting the rotor, sleeves and friction plate mass, $kg * m^2$.

The electromagnetic moment of the asynchronous engine is formed by interaction of current in the rotor winding with the rotating magnetic field [10]. The electromagnetic moment M_d is directly proportional to the electromagnetic power and inversely proportional to the frequency of current

$$M_d = \frac{P_{\partial M} * p}{2 * \pi * f}, \quad (6)$$

where $P_{\partial M}$ is electromagnetic power, p is the number of the stator winding pole pairs, f is alternate current frequency.

When operating a multi-drive chain conveyor, it is considered expedient to distribute the load between the drives evenly [15, 17]. In order to improve the dynamics, the drives are usually placed at the ends of the conveyor. During operation, the loads in the loaded and empty runs are not the same due to the different coefficients of resistance to movement, the difference in loading. The most rational mode of operation will be one in which each drive is loaded on its own run. The implementation of this mode allows using for an empty branch an engine of lower power and, therefore, of smaller dimensions. In case of overloads in the idle run, a part of load can be taken by the loaded run drive. Examples of mathematical and simulation modeling of electromechanical systems of electric drives of chain conveyors were considered in [18, 21].

Results and discussion. A mathematical model of the method of starting the conveyor with two end, head and tail electric drives. For its intended purpose, the first head electric drive (of greater power) works to transport the carrying run of the traction body. At the initial moment of start-up, the head electric drive works on tensioning the carrying run, this process is described by the following equation (for this case the condition $l_{B0} > l_B$ is valid (figure 1)):

$$\begin{cases} J_1 \frac{d\omega_1}{dt} = M_{\mathcal{M}1} - M_{c1} & (7) \\ J_2 \frac{d\omega_2}{dt} = M_{\mathcal{M}2} - M_{c2} & (8) \end{cases}$$

where $M_{\mathcal{M}1}$ is the electromagnetic moment of the first master drive; M_{c1} is the static moment reduced to the first engine shaft; $M_{\mathcal{M}2}$ is the electromagnetic moment of the second slave drive; M_{c2} is the static moment reduced to the second engine shaft.

According to the condition of the method of starting the conveyor, the angular acceleration of rotation of the rotors of the electric engines of the drives is absent.

After reaching the required level of tension of the carrying run at the creeping speed of the traction body, the rotation speed of the rotors of the electric engines gradually increases to the nominal operating conditions. This process is described by the following system of equations:

$$\begin{cases} J_1 \frac{d\omega_1}{dt} = M_{\mathcal{M}1} - M_{c1} - c_1 \int (\omega_1 - \omega_2) dt + c_2 \int (\omega_2 - \omega_1) dt & (9) \\ J_2 \frac{d\omega_2}{dt} = M_{\mathcal{M}2} - M_{c2} - c_2 \int (\omega_2 - \omega_1) dt + c_1 \int (\omega_1 - \omega_2) dt, & (10) \end{cases}$$

where J_1 is the moment of inertia of the first engine; J_2 is the moment of inertia of the second engine; c_1 , c_2 are coefficients of rigidity of the 1st and 2nd electric drives, respectively; ω_1 , ω_2 are angular speeds of rotation of the 1st and 2nd electric drives, respectively.

At the moment of starting, after drawing the carrying run of the traction body, the rotors of both electric engines begin rotating with a certain synchronous angular acceleration.

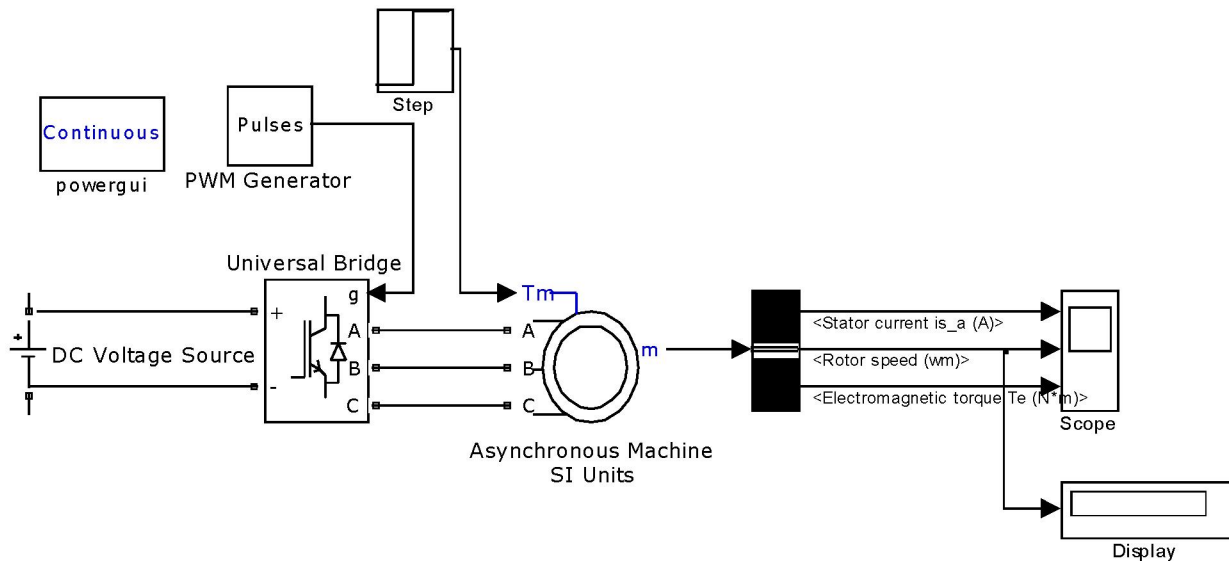


Figure 2 – Model of asynchronous frequency-controlled electric drive of the apron conveyor in MATLAB environment

Conclusion. The proposed mathematical model of a apron conveyor with controlled electric drives in operation starting modes, taking into account the elastic properties of the traction body, which consists in using a frequency-controlled electric drive, allows obtaining the needed starting mode of the conveyor, increasing the efficiency of operation and increasing the life of the electric drive and the conveyor traction-carrying body.

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ПЛАСТИНАЛЫ КОНВЕЙЕР ЭЛЕКТР ЖЕТЕГІНІҢ ІСКЕ ҚОСУ РЕЖИМІНДЕГІ МАТЕМАТИКАЛЫҚ МОДЕЛІ

Аннотация. Үлкен ұзындықтағы көпжетекті пластиналы конвейерді іске қосу күрделі міндет болып табылады, өйткені ол тартқыш органның шамадан тыс босануымен бірге жүреді. Әсіресе, төсемі қисық учаскелері бар, пластиналы конвейерді іске қосу жағдайлары қолайсыз, соның салдарынан жұмыс органының қатандығы тым аз болып келеді, себебі ол оның керілуі мен оған жүктеменің функциясы болып табылады. Аралық жетектердің болуы тартқыш органның бастапқы тартылуын бақылауға мүмкіндік бермейді. Осыған байланысты үлкен ұзындықтағы көпжетекті конвейерді бірқалыпты іске қосуға мүмкіндік беретін тәсілді әзірлеу міндеті өзекті болып табылады.

Бұл жұмыстың мақсаты – конвейер тартқыш органның серпімді қасиеттерін ескере отырып, реттелетін электр жетегі бар екі жетекті пластиналы конвейердің іске қосу режимдерінде математикалық моделін әзірлеу болып табылады. Мақалада пластиналы конвейердің электр жетектерін бірқалыпты іске қосу әдісі ұсынылған. Пластиналы конвейерді іске қосудың ұсынылған тәсілі жиіліктік-реттелетін электр жетегін пайдалана отыра, конвейерді іске қосудың қажетті режимін алуға мүмкіндік береді. Ұсынылған тәсілдің техникалық нәтижесі – іске қосу режимдерінде жұмыс органына динамикалық жүктемелерді төмендету және конвейерлердің жұмыс органының ресурсын ұлғайту есебінен пластиналы конвейерлер жұмысының сенімділігін арттыру болып табылады. Осы тәсілдің негізінде дифференциалдық тендеулердің екі массалық жүйесімен сипатталатын математикалық модель әзірленді. Конвейерді қосу тәсілінің математикалық моделі бойынша Matlab Simulink бағдарламасының пакетінде электржетектің имитациялық моделі құрылған.

Түйін сөздер: көп қозғалтқышты пластиналы конвейер, математикалық модель, конвейердің асинхронды жиіліктік-реттелетін электржетегі, электржетектің бірқалыпты іске қосылуы, қисаю және керілу процестерін кезектестіру.

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МАТЕМАТИЧЕСКАЯ МОДЕЛЬ ЭЛЕКТРОПРИВОДА ПЛАСТИНЧАТОГО КОНВЕЙЕРА В ПУСКОВЫХ РЕЖИМАХ

Аннотация. Пуск многоприводного пластинчатого конвейера большой длины представляет собой сложную задачу, так как он сопровождается чрезмерным расслаблением тягового органа. Особенно неблагоприятны условия пуска пластинчатого конвейера, полотно которого имеет провисающие участки, вследствие чего жесткость рабочего органа, являющаяся функцией его натяжения и нагрузки на нем, относительно мала. Наличие промежуточных приводов не позволяет контролировать первоначальное натяжение тягового органа. В связи с этим актуальна задача разработки способа позволяющего плавно запускать многоприводные конвейера большой длины.

Целью данной работы является разработка математической модели двухприводного пластинчатого конвейера с регулируемым электроприводом в пусковых режимах с учетом упругих свойств тягового органа. В статье представлен разработанный способ плавного пуска электроприводов пластинчатого конвейера. Предложенный способ пуска пластинчатого конвейера заключающийся в использовании частотно-регулируемого электропривода, позволяет получить необходимый режим запуска конвейера. Техническим результатом предлагаемого способа является – повышение надежности работы пластинчатых конвейеров за счет снижения динамических нагрузок на рабочий орган в пусковых режимах и увеличения ресурса рабочего органа конвейеров. На основе данного способа разработана математическая модель, которая описывается двухмассовой системой дифференциальных уравнений. По разработанной математической модели способа пуска конвейера построена имитационная модель электропривода в пакете программы Matlab Simulink.

Ключевые слова: многодвигательный пластинчатый конвейер, математическая модель, асинхронный частотно-регулируемый электропривод конвейера, плавный пуск электропривода, чередование процессов провисания и натяжений.

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