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ABOUT THE DISTRIBUTED MODEL OF COMPOSITE CONVEYOR

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Abstract. The problem of energy consumption of composite conveyors is considered. A distributed model of control of production lines is proposed for use. The model of control of composite conveyors in partial derivatives is described. The problem of optimal control of conveyors with leading and driven lines is formulated.

Key words: composite conveyors, production lines, partial derivatives models, models of optimal control.

With the advancement of automated transport systems in modern production, an important question about managing these installations has arisen. One of the well-known types of this transport is the belt conveyor. A modern composite belt conveyor is a complex automation object, which is characterized by branching in space, multiply connectedness and the presence of many technological processes and operations. Today the most common models of enterprise management with production lines are discrete-event models (DES-model), queuing models (QN-model), fluid models (Fluid-model) and models using partial derivatives (PDE-model). The analysis carried out in [1] clearly demonstrates the advantage of PDE-models, in particular, working with the production of an in-line type of organization that does not function continuously.

PDE-models due to the control and regulation of the incoming flow and productivity of processing objects of labor embody two basic concepts of production: the minimum deviation of output from existing demand and minimization of stocks of work in progress [2]. The position of the subject of labor in the technological route is characterized by the coordinate $S \in [0; S_d]$ (Fig. 1). The initial condition determines the number of objects of labor at the time point at each technological operation.

Production lines are part of technological routes that can be interconnected and diverge. The question of describing production lines with branching, even in its simplest form (Fig. 1), remains relevant.

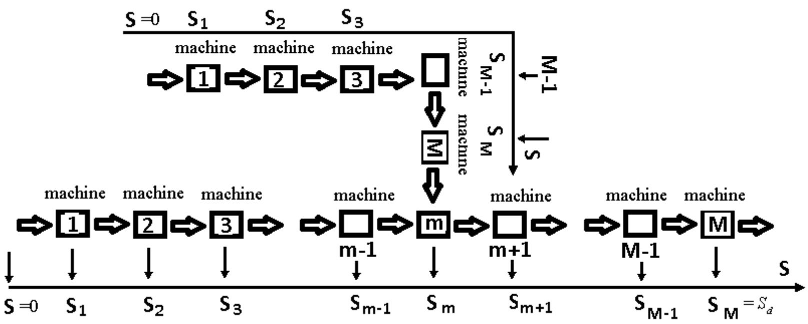

Fig.1. Scheme of a binodal production conveyor line

For increasing productivity, often used branched conveyor lines (Fig. 1). In the diagram over, the lower conveyor is a leading line; the upper is a driven (supplementary) line. As a rule, the lead line contains the critical path for manufacturing the product.

The m-th technological operation of the leading line receives objects of labor from the (m-1)-th technological operation of the leading line and the M-th technological operation of the supplementary line. The system of equations describing the interaction of related lines has the form for an additional driven production line [2 - 3]:

$$\frac{\partial[\chi_1]_0(t,S_1)}{\partial t}+\frac{\partial[\chi_1]_1(t,S_1)}{\partial S_1}=0,$$

$$[\chi_1]_1(t,S_1)=a_1[\chi_2]_0(t,S_1) \tag{1}$$

with initial

$$[\chi_1]_0(t_{01},S_1)=\Psi_1(S_1),$$

or boundary conditions

$$[\chi_1]_0(t,S_{01})=\Phi_1(t),$$

and for the leading production line:

$$\frac{\partial[\chi_2]_0(t,S_2)}{\partial t}+\frac{\partial[\chi_2]_1(t,S_2)}{\partial S_2}=\delta(S_2-S_{02})[\chi_1]_1(t,S_{d1}), \tag{2}$$

$$[\chi_2]_1(t,S_2)=a_2[\chi_2]_0(t,S_2), \tag{3}$$

with initial

$$[\chi_2]_1(t,S_2)=a_2[\chi_2]_0(t,S_2) \ ,$$

or boundary conditions

$$[\chi_2]_0(t,S_{02})=\Phi_2(t).$$

The technological position with the coordinate $S_k=S_{dk}$ corresponds to the degree of readiness of the object of labor, that is, the state to which the object of labor must correspond when leaving the production conveyor line according to production and technological documentation. The parameters $[\chi_k]_0(t,S_k)$ and $[\chi_k]_1(t,S_k)$ are interconnected by a coefficient a_k that sets the speed of movement of the conveyor line. For conveyors with constant speed a_k = const [4].

Taking into account the introduced notation, the balance equation (2) was written for the leading line in a dimensionless form

$$\frac{\partial[\theta_2]_0(\tau,\xi_2)}{\partial\tau}+g_2\frac{\partial[\theta_2]_0(\tau,\xi_2)}{\partial\xi_2}=\delta(\xi_2-\xi_{02})g_1[\theta_1]_0(\tau,1), \tag{4}$$

$$[\theta_2]_0(\tau_{02},\xi_2)=\psi_2(\xi_2), \tag{5}$$

$$[\theta_2]_0(\tau,\xi_{02})=\vartheta_2(\tau) \ . \tag{6}$$

The function $[\theta_1]_0(\tau,1)$ is unknown and is determined by solving the balance equation (1) for an additional line, which can be written in dimensionless form [3]:

$$\frac{\partial[\theta_1]_0(\tau,\xi_1)}{\partial\tau}+g_{01}\frac{\partial[\theta_1]_0(\tau,\xi_1)}{\partial\xi_1}=0, \ g_{01}=g_1\frac{S_{d2}}{S_{d1}}, \tag{7}$$

$$[\theta_1]_0(\tau_{01},\xi_1)=\psi_1(\xi_1) \ , \tag{8}$$

$$[\theta_1]_0(\tau,\xi_{01})=\vartheta_1(\tau) \ . \tag{9}$$

The general solution of equation (7) is a function of the first integral:

$$[\theta_1]_0(\tau,\xi_1) = [\theta_1]_0(\xi_1 - g_{01}\cdot\tau).$$

Taking into account the initial condition (8) and the boundary condition (9), the solution (7) has the form

$$[\theta_1]_0(\tau,\xi_1) = [\theta_1]_0(\xi_1 - g_{01}\cdot\tau) = \psi_1(r_1 + \xi_{01}), \tag{10}$$

or

$$[\theta_1]_0(\tau,\xi_1) = [\theta_1]_0(\xi_1 - g_{01}\cdot\tau) = \vartheta_1\left(\tau_{01} - \frac{r_1}{g_{01}}\right). \tag{11}$$

for the case that there is no discontinuity of the solution $[\theta_1]_0(\tau,\xi_1)$, the equality holds

$$\psi_1(r_1 + \xi_{01}) = = \vartheta_1\left(\tau_{01} - \frac{r_1}{g_{01}}\right) \tag{12}$$

Substituting $[\theta_1]_0(\tau,1)$ from the solution for the additional conveyor line into the equation for the leading line, we obtain a closed system of equations [5]. The system of equations (7) - (9) corresponds to the system of characteristics:

$$\frac{d\xi_2}{d\tau} = g_2 \quad , \tag{13}$$

$$g_2 \frac{d[\theta_2]_0(\tau,\xi_2)}{d\xi_2} = \delta(\xi_2 - \xi_{02}) g_1 [\theta_1]_0(\tau,1) \quad , \tag{14}$$

$$[\theta_2]_0(\tau_{02},\xi_2) = \psi_2(\xi_2),$$

$$\xi_2 - g_2\tau = C_2 \tag{15}$$

Express $\tau = \dfrac{\xi_2 - C_2}{g_2}$ from (15) and substitute in (14):

$$[\theta_2]_0(\tau,\xi_2) = \int_0^{\xi_2} \delta(\eta - \xi_{02}) \frac{g_1}{g_2} [\theta_1]_0\left(\frac{\eta - C_2}{g_2}, 1\right) d\eta = = H(\xi_2 - \xi_{02}) \frac{g_1}{g_2} [\theta_1]_0\left(\frac{\xi_2 - C_2}{g_2}, 1\right) + C_3$$

Solution $[\theta_2]_0(\tau,\xi_2)$ for the function:

$$[\theta_1]_0(\tau,0) = \vartheta_1(\tau) = 1; \; [\theta_1]_0(0,\xi_1) = \psi_1(\xi_1) = 0; \tag{16}$$

$$[\theta_2]_0(0,\xi_2) = \psi_2(\xi_2) = \frac{1}{3}(2 + \sin(2\pi\xi_2)) \tag{17}$$

with the source of receipt of objects of labor on the main line at the point presented in Fig.2.

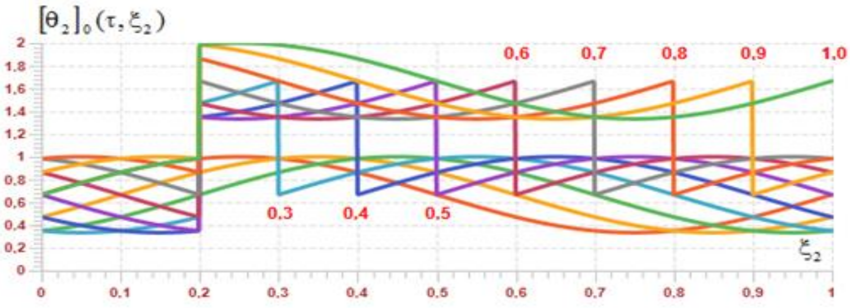

Fig.2. The distribution of objects of labor $[\theta_2]_0(\tau,\xi_2)$ according to the technological positions of the conveyor for points in time $\tau=(t/T_d)=\{0.0;0.1;0.2;....0.9;1.0\}$ with $g_2=g_1=1.0$, $S_{d2}=0.2S_{d1}$

The change in time of the number of objects of labor in the inter-operational basis of the technological positions of the main conveyor line, defined by the coordinate $\xi_2=(S/S_d)=\{0.0;0.1;0.2;....0.9;1.0;\}$ is shown in Fig.3. Starting from a time point τ > 0.2, the technological positions of the main production line show the effect of the operation of an additional conveyor line. The jump of the function $[\theta_2]_0(\tau,\xi_2)$ for the technological position ξ_2 = 0.2 at the time τ = 0.2 spreads with the speed of the movement of the conveyor g_2 to the subsequent technological operations.

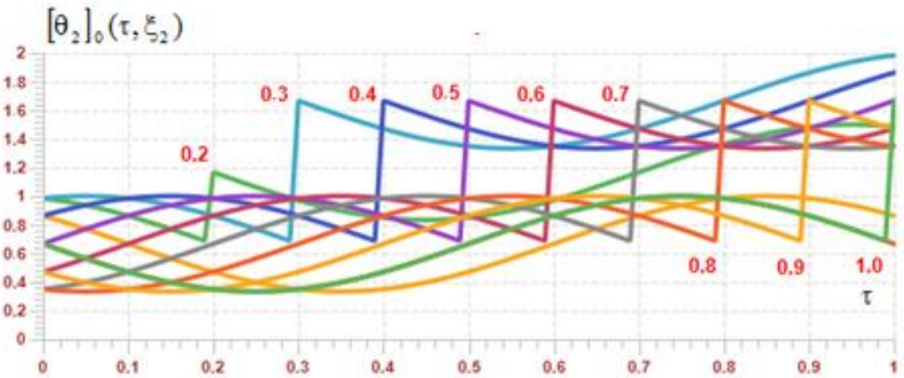

Fig.3. The dependence of the number of objects of labor $[\theta_2]_0(\tau,\xi_2)$ on the technological position of the conveyor from the time when $g_2=g_1=1.0$, $S_{d2}=0.2S_{d1}$, for the values of the coordinate $\xi=(S/S_d)=\{0.0;0.1;0.2;....0.9;1.0;\}$

The characteristic equation (13) determines the trajectories of the movement of individual objects of labor along the technological route along the main conveyor line [6]. As expected, the movement of a separate object of labor along the trajectory is carried out with a constant speed equal to the speed of movement of the conveyor line. Equation (13) allows to calculate the duration of the production cycle of the product (Fig.4). The duration of the production cycle is equal to the period of time during which the object of labor goes from the first technological position to the last.

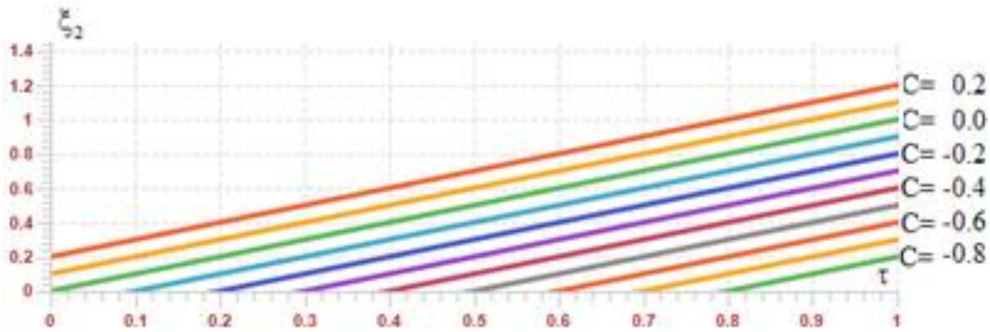

Fig.4. The family of characteristics $\xi = g\tau + C$, $C = \{0.2;0.1;0.0;....-0.7;-0.8;\}$, $g_2 = g_1 = 1.0$, $S_{d2} = 0.2S_{d1}$

The results of the study are basic for the development of production control systems for the conveyor type, consisting of the main and a variety of auxiliary lines. The main line operates in continuous mode and additional conveyor lines in on / off mode, which allows you to adjust the output of finished products [7].

It should be noted that the results of the work are of scientific and practical interest for the design of speed control systems for the belt of transport conveyor systems, which are widely used in the mining industry [8]. An important result of this work is also a method for calculating the duration of the production cycle, based on the use of the characteristic equation. This method allows you to build the dependence of the duration of production on the distribution of objects of labor along a conveyor line at a point in time, which determines the receipt of the first object of labor for processing at the first technological operation.

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