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Development of the Calculation Methodology for the System of Automatic Centering of the Belt on a Drum with Curvilinear Generatrix

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Abstract. *The research on the development of the calculation methodology for the system of automatic centering of the belt on a drum with curvilinear generatrix was conducted. The structural scheme for the system of belt centering on the drum was proposed. Recommendations on the choice of conveyor parameters and the system for stabilizing the belt on the drum are provided to ensure trouble-free operation of the transport installation.*

Keywords: *belt conveyor, transient process, lateral belt run-off speed and value, drum with curvilinear generatrix, system of automatic belt centering.*

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I. Introduction

The relevance of the problem and its connection to important scientific and practical tasks. The lateral belt run-off on the receiver device drum has repeatedly become the cause of major emergencies on the conveyor transport.

While changing the transportation length on an operating belt conveyor [1] the perpendicularity violation of the belt axis relative to the drum axis leads to the lateral belt run-off causing an emergency situation.

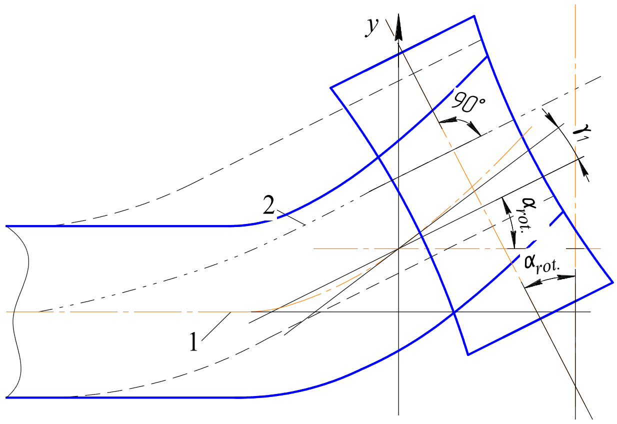
It is known that lateral belt run-off lessens if the drum has the curvilinear generatrix [2].

The development of a system of automatic belt centering on a drum with a curvilinear generatrix will prevent the occurrence of emergency situations on a conveyor transport.

Review of the recent research and publications.

In the recent works [3;4] research on the formulation of the mathematical model of the lateral belt run-off transient process on the drum with the slight curvilinearity of the generatrix.

It was established that the lateral belt run-off is to be viewed with the account for the regularities of its movement on the drum and the roller supports mounted on the entering branch of the conveyor. (Fig. 1).



1 - belt position in the transient mode; 2 – belt position in the stationary mode
Fig. 1. Scheme of lateral belt run-off on the drum

For a practically important case, when the length of belt wrap on a drum exceeds 20 ÷ 30 *cm*, the transient process of the belt run-off is written (the drum generatrix is presented in the form of a cut-off ellipse) [3; 4]:

$$\left(T_0^{el.}\lambda+1\right)y=K_0\alpha_{rot.},\ m \qquad (1)$$

where $\lambda=d/dt$ - differentiation operator; $T_0^{el.}$ - characteristic time of the controlled unit (belt), (*s*); K_0 – transfer ratio for the drum swivel angle, (*m*).

$$T_0^{el.}=S_b\left(K_{curvil.}^{ellipse}+1\right)/\left(q_b\cdot c_{f.g.}\cdot V_b\cdot g\right),\ s \qquad (2)$$

$$K_o=S_b/\left(q_b\cdot c_{f.g.}\cdot g\right),\ m \qquad (3)$$

where S_b - belt tension, (*N*); q_b - mass per unit weight of the belt, (*kg/m*); $c_{f.g.}$ - slope ratio of the linear part of the friction-glide diagram $c_{f.g.}$ = 10-30 [5]; V_b - belt speed, (*m/s*); $K_{curvil.}^{ellipse}$ - drum curvilinearity coefficient; g - gravitational acceleration, (*m/s*^{2})

$$K_{curvil.}^{ellipse}\cong\sqrt{1-k+b^2/\left(a^2-y^2\right)} \qquad (4)$$

where $k=b^2/a^2$ - ellipse compression ratio; a - half the length of the minor axis of the generatrix of a drum in the form of an ellipse, (*m*); b - half the length of the major axis of the generatrix of a drum in the form of an ellipse, (*m*).

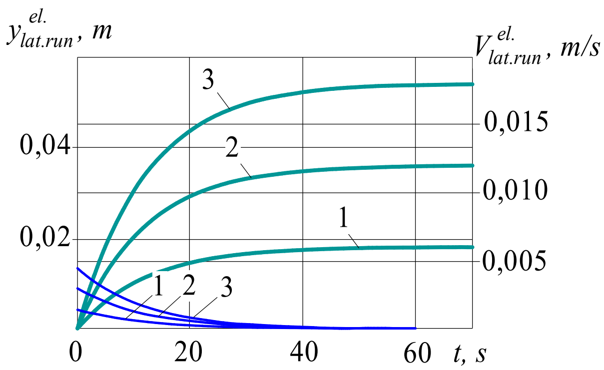
Velocity of the belt lateral run-off from the drum

$$V_{lat.run.}^{el.}=dy/dt=\alpha_{rot.}V_b\exp\left(-t/T_0^{el.}\right)/\left(K_{curvil.}^{ellipse}+1\right),\ m/s \qquad (5)$$

where $\alpha_{rot.}$ - drum rotation angle, (*rad*).

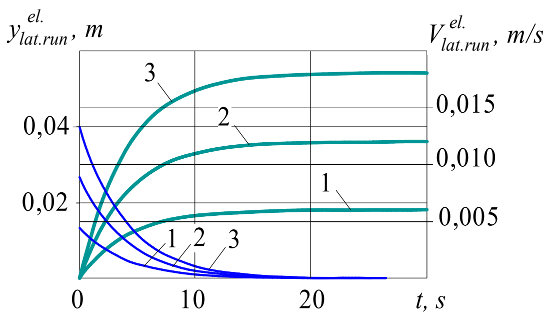
Value of the belt lateral run-off from the drum

$$y_{lat.run.}^{el.}=K_0\alpha_{rot.}\left[1-\exp\left(-t/T_0^{el.}\right)\right],\ m \qquad (6)$$



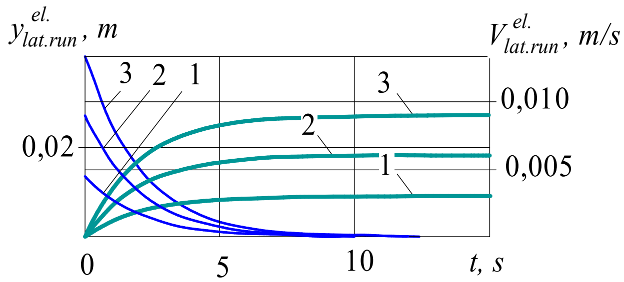
1 - $\alpha_{rot.}=0,01$ ***rad*; 2 -** $\alpha_{rot.}=0,02$ ***rad*; 3 -** $\alpha_{rot.}=0,03$ ***rad***

Fig. 2. Graphs of changing belt run-off velocity (solid line) and value (dotted line) when S_b= 400 *N*; q_b =2 *kg/m*; $V_b=0,3$ *m/s*; $c_{f.g.}=11,1$; $K_{curvil.}^{ellipse}=1,014$, obtained theoretically.



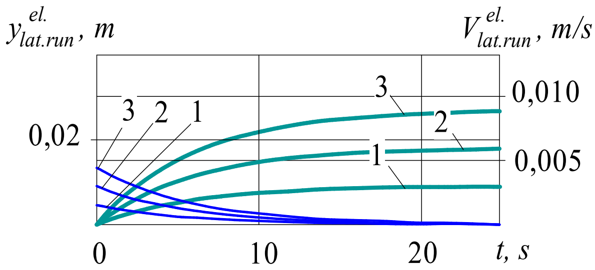
1 - $\alpha_{rot.}=0,01$ ***rad*; 2 -** $\alpha_{rot.}=0,02$ ***rad*; 3 -** $\alpha_{rot.}=0,03$ ***rad***

Fig. 3. Graphs of changing belt run-off velocity (solid line) and value (dotted line) when S_b= 400 *N*; q_b =2 *kg/m*; $V_b=0,9$ *m/s*; $c_{f.g.}=11,1$; $K_{curvil.}^{ellipse}=1,014$, obtained theoretically.



1 - $\alpha_{rot.} = 0{,}01$ ***rad*****; 2 -** $\alpha_{rot.} = 0{,}02$ ***rad*****; 3 -** $\alpha_{rot.} = 0{,}03$ ***rad***

Fig. 4. Graphs of changing belt run-off velocity (solid line) and value (dotted line) when S_b= 200 *N*; q_b =2 *kg/m*; $V_b = 0{,}9$ *m/s*; $c_{f.g.} = 11{,}1$; $K^{ellipse}_{curvil.} = 1{,}014$, obtained theoretically.



1 - $\alpha_{rot.} = 0{,}01$ ***rad*****; 2 -** $\alpha_{rot.} = 0{,}02$ ***rad*****; 3 -** $\alpha_{rot.} = 0{,}03$ ***rad***

Fig. 5. Graphs of changing belt run-off velocity (solid line) and value (dotted line) when S_b= 200 *N*; q_b =2 *kg/m*; $V_b = 0{,}3$ *m/s*; $c_{f.g.} = 11{,}1$; $K^{ellipse}_{curvil.} = 1{,}014$, obtained theoretically.

Figures 2 to 5 show the graphs of changing belt run-off lateral velocity and value on the drum with a slight curvilinearity at different drum rotation angles and present parameters.

Figures 6 and 7 show graphs of changing time and value of the belt run-off on the warped drum which were obtained experimentally. [6].

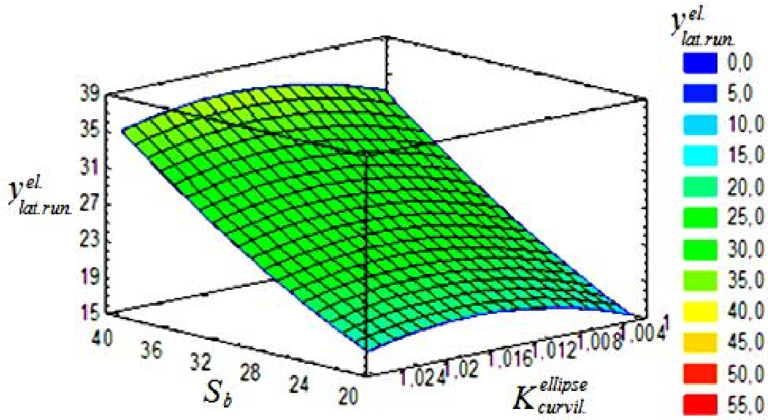


Fig. 6 - Response surface of the belt run-off value on the warped drum from to the belt tension and drum curvilinearity factor when $\alpha_{rot.} = 0{,}02$ *rad*, V_b = 0,6 *m/s*

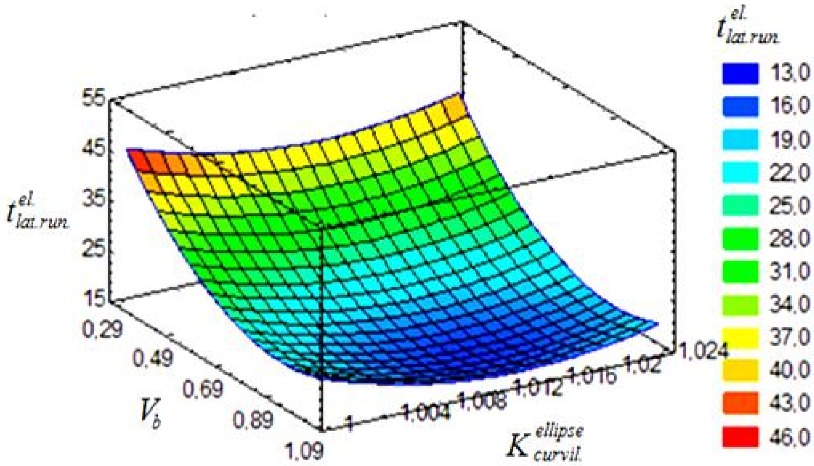
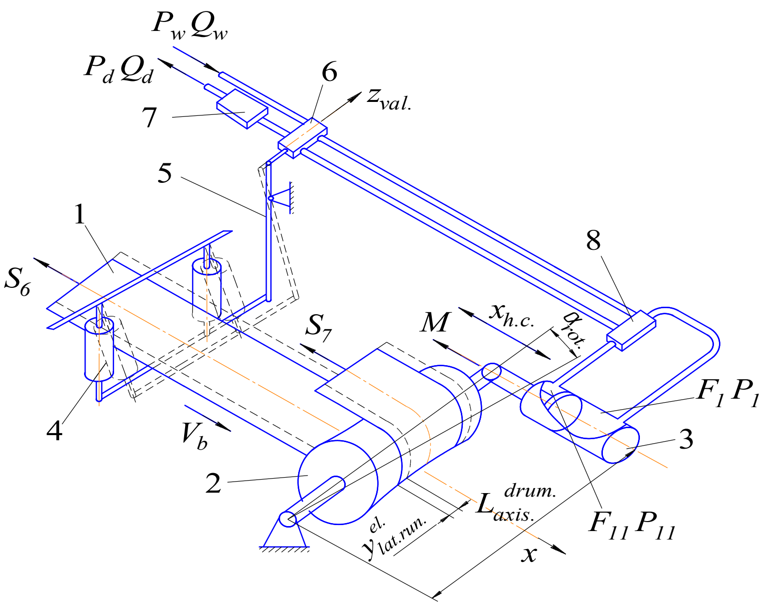


Fig. 7 - Response surface of the belt run-off time on the warped drum from to the belt tension and drum curvilinearity factor when $m_{T.D.}$ = 30kg, $\alpha_{rot.} = 0,02$ rad.

In works [1; 2; 7] the design of a mobile conveyor station with a system of automatic belt centering on the drum with a curvilinear generatrix was proposed (Fig. 8)



1 - belt; 2 – drum with curvilinear generatrix; 3 - hydraulic cylinder; 4 – belt-positioning sensors; 5 – lever system; 6 - spool-type valve; 7 – flow controller; 8 - hydraulic lock

Fig. 8. Basic diagram of the automatic belt centering on the drum

The analysis of recent studies and publications results indicates that there are all the preconditions for developing the calculation methodology for the system of automatic belt centering on the drum with curvilinear generatrix.

Objective of the study. On the basis of all the research conducted, to develop the calculation methodology for the system of automatically belt centering on the drum with a curvilinear generatrix.

Statement of the basic materials.

The structural diagram of the automatic belt centering system on the drum with curvilinear generatrix can be presented as follows

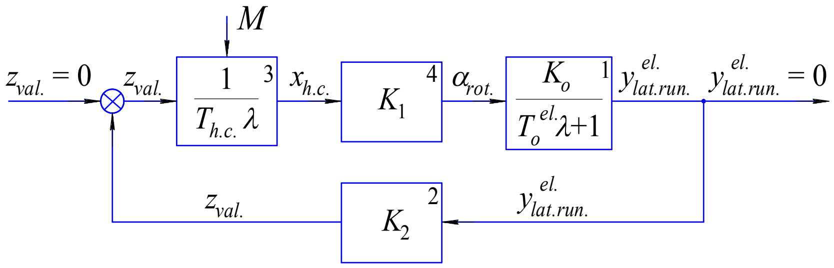


Fig. 9. Structural diagram of the automatic belt centering system on the drum with curvilinear generatrix

Link transfer function 1 which indicates the transient process of the belt run-off on the drum after the transformation will be written as:

$$W(\lambda)^{el.}_{d.b.} = K_0 / \left(T_0^{el.}\lambda + 1\right), \text{м} \quad (7)$$

The transfer function of the open-cycle control system for the belt positioning on the drum [1]

$$W(\lambda)_{syst.} = K_{syst.} / \left[\lambda\left(T_0^{el.}\lambda + 1\right)\right] \quad (8)$$

where $K_{syst.} = K_0 K_1 K_2 / T_{h.c.}$ - open-cycle control system amplification factor, (s^{-1}); $K_1 = 1/L^{drum.}_{axis.}$ - lever system transfer factor when extending or retracting the piston rod of the servomotor and converting its progressive motion into the drum sweep angle, (m^{-1}) [1]; K_2 - lever system transfer factor that converts the belt run-off into the valve offset [1]; $T_{h.c.}$ - time constant of the servomotor (hydraulic cylinder) during the piston movement [1], (*s*).

Time constant of the servomotor during the piston movement for the rod extension [1]:

$$T'_{h.c.} = \sqrt{\left[\nu_{w.b.}\left(F_1^3 + F_{11}^3\right)\right] / \left[2g\left(F_{11}P_w - F_{11}P'_s + M\right)a^2_{val.}\mu_v^2\right]}, s \quad (9)$$

Time constant of the servomotor during the rod retraction time constant of the servomotor during the rod retraction [1]

$$T''_{h.c.} = \sqrt{\left[\nu_{w.b.}\left(F_1^3 + F_{11}^3\right)\right] / \left[2g\left(F_{11}P_w - F_1 P''_s - M\right)a^2_{val.}\mu_v^2\right]}, s \quad (10)$$

where μ_v - outflow factor for the valve ports; $a_{val.}$ - total width of the valve ports, (*m*); g - gravitational acceleration, (m/s^2); $\nu_{w.b.}$ - working body relative density, (N/m^3); P_w - progress pressure in the hydraulic system, (N/m^2); F_1 - servomotor piston area, (m^2); F_{11} - piston area without servomotor rod area, (m^2); P'_s, P''_s - intake pressure of the flow controller when extending and retracting the piston rod of the servo motor, (N/m^2); *M* - load on the rod of the actuating cylinder, which depends on the belt tension, (*N*).

Servomotor oil flow $Q_{h.syst.}$, spool-type valve opening ratio $\Delta z_{val.}$ and servomotor time constant $T_{h.c.}$ are related by the dependence [1]

$$Q_{h.syst.} = \frac{\Delta z_{val.}}{T_{h.c.}} \sqrt{\frac{F_1^3 + F_{11}^3}{F_1 + F_{11}}}, \ m^3/s. \quad (11)$$

To ensure the satisfactory control quality of the damping of the transient process within 1 period Для обеспечения удовлетворительного качества регулирования затухание переходного процесса за 1 период ($\eta_{damp.}$ = 90%) system parameters shall subject to the condition [1]

$$K_{syst.} \leq 3{,}2 / T_0^{el.}, s^{-1} \quad (12)$$

By putting components into equation (11) and performing the transformations, we shall obtain the required oil flow rate in the hydraulic system of the belt centering system, which ensures high-quality and stable operation

$$Q_{h.syst.} \leq \frac{3{,}2 \cdot V_b \cdot L^{drum.}_{axis.} \cdot \Delta z_{val.}}{K_2\left(K^{ellipse}_{curvil.} + 1\right)} \left(\frac{q_b \cdot c_{f.g.} \cdot g}{S_b}\right)^2 \cdot \left[\frac{F_1^3 + F_{11}^3}{F_1 + F_{11}}\right]^{1/2}, \ m^3/s \quad (12)$$

II. Conclusions

1. The transient process of the belt run-off on the drum with a slight curvilinearity of the generatrix is described by the equation corresponding to a first-order aperiodic link.
2. With increasing the drum rotational angle, and the conveyor belt speed and tension, the amount of the lateral run-off and its speed increase.
3. With increasing the mass per unit length of the belt, the friction-glide factor of the belt on the rollers, the amount of the lateral run-off decreases.
4. With increasing of the drum curvilinearity, there is a decreasing tendency for the amount of the belt run-off.
5. Drum curvilinearity is limited by the existing width tension difference and the rigidity of the flat belt.
6. Stable and high-quality operation of the belt stabilization system on the drum can be ensured by defining the required oil flow in the belt centering system.

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