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Development of the Calculation Methodology for the Belt Load When Changing the Conveyor Transportation Length

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Abstract: *The studies on the development of the methodology for calculating the occurring belt load during the change of the conveyor transportation length with the stopped and working drive have been presented. Recommendations were given on the choice of the belt conveyor operation modes with varying transportation lengths to ensure the trouble-free operation of the conveyor. It has been determined that for the slight angles of the conveyor setting, the change in the belt tension on the drum of the extending conveyor mobile station with the stopped drive is bigger than for the extending conveyor with the working drive. The increase in the belt static tension on the mobile station drum during the extension of the conveyor lasts as long as the transportation length changes. The increase in the dynamic tension lasts as long as the mobile station acceleration occurs.*

Keywords: *belt conveyor, calculation methodology, tensioning belts, transportation length change, stopped and working drive.*

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The relevance of the problem and its connection to important scientific and practical tasks.

The creation and implementation of belt conveyors with varying transportation length (BCVTL) allowed for shortening the time for technological operations performed for reducing and extending of the conveyor length, decreasing the number of load transfer devices, cutting down energy consumption during transportation of loads [1]. The use of the belt conveyors with varying transportation length (BCVTL) at the mine n.a. A.F. Zasyadko allowed to increase the speed of the mine opening [1].

The use of BCVTL in longwall face of Prosper-Haniel mine allowed for an increase in labor productivity [2].

Observations of the work of the heading (BCVTL) at the mine n. a. A. F. Zasyadko, showed that during the conveyor extension with the stopped drive there were belt ruptures. At the same time, if the transportation length was changed while the conveyor drive was working, there were no ruptures.

It is seen as possible to ensure the trouble-free operation of (BCVTL0 only when making the proper choice of design parameters and operation modes which are able to provide for the minimum belt load. To determine the belt load that occurs while changing the conveyor transportation length is a relevant scientific and practical task.

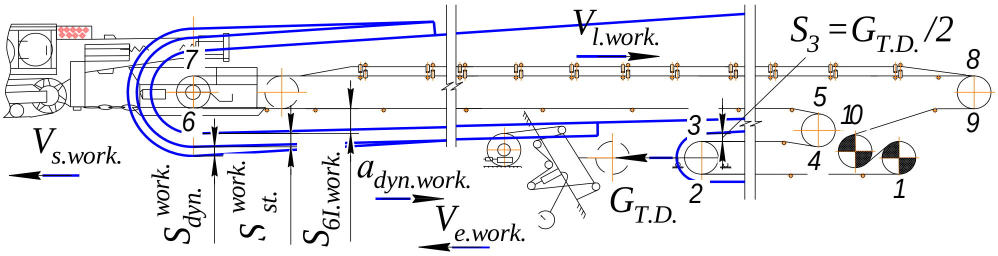
Review of the recent research and publications.

In the work [2] it is noted that to avoid having to increase the strength of the belt (BCVTL) it is necessary to ensure the proper choice of design parameters and operating modes.

It was established that during the transportation length change of (BCVTL) on the mobile station drum there is an increase in the belt tension associated with the occurring elastic deformation of the belt [3].

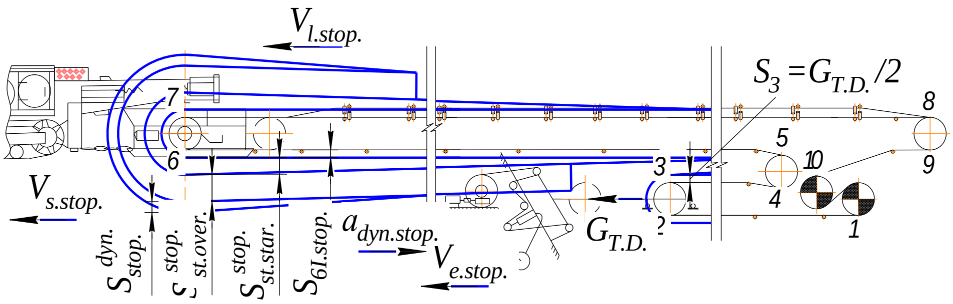
In the work [3] it is pointed out that the value of the static increase in the belt tension during a conveyor extension is affected by the change in the belt speed; the dynamic increase in the belt tension during a conveyor extension is affected by the change in the belt acceleration on the laden and empty arms, as well as the static belt tension (Fig.1, Fig.2).

The increase in the static tension of the belt on the drum of the mobile station during the extension of the conveyor lasts as long as the transportation length changes. The increase in the dynamic tension lasts as long as the acceleration of the mobile station occurs.



$S^{work.}_{dyn.}$ - change in the belt dynamic load (BCVTL) with a working drive, $S^{work.}_{st.}$ - change in the belt static load (BCVTL) with a working drive, $S_{6I.work.}$ - belt tension in point 6 before the extension (BCVTL) with a working drive, $V_{s.work.}$ - mobile station movement speed (BCVTL) with a working drive, $V_{e.work.}$ - speed of an empty arm (BCVTL) with the working drive, $V_{l.work.}$ - speed of a laden arm (BCVTL) with the working drive, $a_{dyn.e.}$ - dynamic speed of the elastic strain propagation on the empty arm (BCVTL) with the working drive, $G_{T.D.}$ - tensioner device force, S_3 - belt tension in point 3

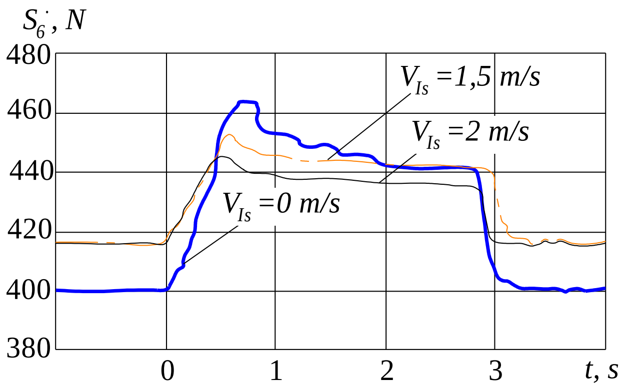
Fig. 1 - The design scheme of the occurring belt tension during the extension (BCVTL) with a working drive



$S^{dyn.}_{stop.}$ - change in the belt dynamic load (BCVTL) with the stopped drive, $S^{stop.}_{st.star.}$ - change in the belt static load (BCVTL) with the stopped drive in the start of movement stage, $S^{stop.}_{st.over.}$ - change in the belt static load (BCVTL) with the stopped drive in overclocking stage, $S_{6I.stop.}$ - belt tension in point 6 before the extension (BCVTL) with the stopped drive, $V_{s.stop.}$ - mobile station movement speed (BCVTL) with the stopped drive, $V_{e.stop.}$ - speed of an empty arm (BCVTL) with the stopped drive, $V_{l.stop.}$ - speed of a laden arm (BCVTL) with the stopped drive, $a_{dyn.e.}$ - dynamic speed of the elastic strain propagation on the empty arm (BCVTL) with the stopped drive, $G_{T.D.}$ - tensioner device force, S_3 - belt tension in point 3

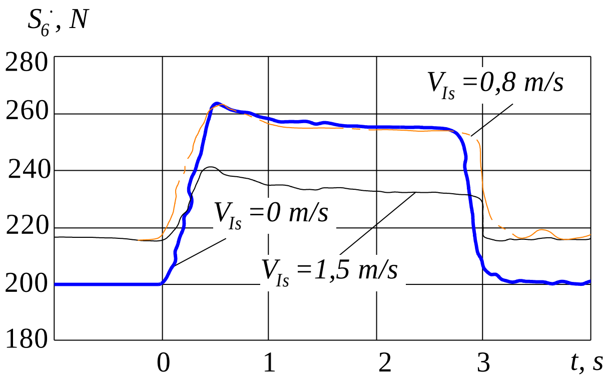
Fig. 2 - The design scheme of the occurring belt tension during the extension (LKIDT) with the stopped drive

Figures 3 and 4 show the graphs of the changes in the belt load on the mobile station drum when extending the conveyor which were obtained experimentally.



$V_{I.s.}$ **- belt speed created by the drive (BCVTL) before extending**

Fig. 3 - Graphs of the change in the belt load on the mobile station drum of the pilot conveyor for various belt speeds created by the conveyor drive, depending on the time of transportation length change with 400 H tensioner device force



$V_{I.s.}$ **- belt speed created by the drive (BCVTL) before extending**

Fig. 4 - Graphs of the change in the belt load on the mobile station drum of the pilot conveyor for various belt speeds created by the conveyor drive, depending on the time of transportation length change with 200 H tensioner device force

The analysis of the results of the recent studies and publications indicates that there are all pre-conditions for the development of a method for calculating the occurring belt load during the conveyor extension with the stopped and working drive.

Objective of the study. On the basis of the research conducted, to develop a method for calculating the occurring belt load during the conveyor extension with the stopped and working drive. To give recommendations on the choice of operation modes (BCVTL) to ensure trouble-free work of a conveyor.

Presentation of the main material.

On the basis of the studies given in the work [3], a method for calculating the occurring belt load during the conveyor extension with the stopped and working drive has been developed.

I. The calculation methodology for the belt load during the conveyor extension with the stopped drive

1). We shall determine the speed and acceleration of the mobile station

$$V_{s.stop.} = \left(M_s - \aleph_{stop.}\right)\left[1 - \exp\left(-\Re t / \Im_{stop.}\right)\right] / \Re, \ \ m/s;$$

$$j_{s.stop.} = \left(M_s - \aleph_{stop.}\right)\exp\left(-\Re t / \Im_{stop.}\right) / \Im_{stop.}, \ \ m/s^2;$$

$$\Re = 2\beta_{el.mot.} / \left(R_{ast.} i_{rum.gear.}\right), \ \ m/s;$$

$$\aleph_{stop.} = R_{ast.} \cdot i_{rum.gear.}\left[2\Omega_e l_{3-6} + g\left(m_{hea.mach.} + m_{T.D.} + m_s + 6m_{drum.}\right)/2\right], \ N{\cdot}m;$$

$$\Im_{stop.} = \frac{2\left(J_{r.el.mot.} + J_{1.gear.wh.} + J_{2.gear.wh.} i_{rum.gear.}\right)}{R_{ast.} i_{rum.gear.}} + R_{ast.} i_{rum.gear.}\left(4\Omega_e l_{3-6}/g + \right.$$

$$\left. + m_{hea.mach.} + m_{T.D.} + m_s + 6m_{drum.}\right)/2, \ kg{\cdot}m;$$

where M_s - the starting moment of the propelling motor of the heading machine which moves the mobile station, ($N{\cdot}m$); $m_{drum.}$ - drum mass, (kg); $\beta_{el.mot.}$ - the coefficient describing the mechanical characteristic slope of the electric motor of the heading machine carrier, ($N{\cdot}m/s$); $R_{ast.}$ - the radius of the track driving asterisk of the heading machine running gear (m); $i_{rum.gear.}$ - gear ration of the heading machine running gear; $m_{hea.mach.}$ - the mass of the heading machine that moves the mobile station, (kg); $m_{T.D.}$ – the mass of the movable carriage of the telescopic device, identified with the tensioner device force, (kg); m_s - mobile station mass, (kg); $J_{1.gear.wh.}$, $J_{2.gear.wh.}$ - the inertia moment of the respective first and second gear wheels of the heading machine travel gearbox ($kg{\cdot}m^2$); $J_{r.el.mot.}$ - the inertia moment of the rotor of the heading machine propelling motor ($kg{\cdot}m^2$).

2). We shall determine the speed and acceleration of an empty conveyor arm

$$V_{e.stop.} = V_{s.stop.}\left(\Lambda \pm \sqrt{\Lambda^2 - \Phi}\right)/\mathrm{P}, \ m/s;$$

$$j_{e.stop.} = j_{s.stop.}\left(\Lambda \pm \sqrt{\Lambda^2 - \Phi}\right)/\mathrm{P}, \ m/s^2;$$

$$\mathrm{P} = \left[\left(\Omega_e l_{9-6} + \Omega_l l_{7-8}\right)/g + 5 m_{drum.} + m_{red.dr.con.}\right]/2, \ kg;$$

$$\Phi = \left[\left(\Omega_e l_{9-2} + l_{3-6}\Omega_n + \Omega_l l_{7-8}\right)/g + 5 m_{drum.} + m_{red.dr.con.}\right]\times$$

$$\times\left[\left(\Omega_l l_{7-8} + \Omega_e l_{9-2} - \Omega_e l_{3-6}\right)/g + m_{red.dr.con.}\right], \ kg^2;$$

$$\Lambda = \left(\Omega_l l_{7-8} + \Omega_e l_{9-2}\right)/g + 2{,}5 m_{drum.} + m_{red.dr.con.}, \ kg,$$

where Ω_l - specific static resistance of the movement of a laden conveyor arm, (N/m); Ω_e - specific static resistance of the movement of aan empty conveyor arm, (N/m); $l_{7-8}, l_{9-2}, l_{9-6}, l_{3-6}$ - the length of the conveyor sections corresponding to the distance between the characteristic points, (m); $m_{red.dr.con.} = k\left(GD\right)_r^2 i_r^2/\left(gD_{dr.drum.}^2\right)$ - reduced conveyor mass, (kg) [3]; k - the coefficient taking into account the inertia of the conveyor drive gearbox, equals 1,2-1,3; $\left(GD\right)_r$ - the rotative moment of the rotor of the conveyor drive motor, ($N{\cdot}m$); $i_{gear.}$ - gear ration of the conveyor drive gearbox; $D_{dr.drum.}$ - the diameter of the conveyor drive drum.

3). We shall determine the time of belt stretching, associated with the increase in the belt static load, from the mobile station drum to the conveyor tensioner device during the starting stage $t = t_{star.}$,

$$\left(t_{star.} - e^{-\frac{\Re}{\Im_{stop.}} t_{star.}}\right) = \frac{\mathrm{P}\cdot\Re\cdot l_{3-6}\left(\Omega_e l_{3-6} + G_{T.D.}\right)}{2E_{0.st.}\left(M_s - \aleph_{stop.}\right)\left(\Lambda \pm \sqrt{\Lambda^2 - \Phi}\right)}, \ s.$$

4). We shall determine the value of the change in the static belt load for the time from $t = 0$ *till* $t = t_{star.}$ *(during the starting stage)*

$$S_{st.stop.}^{star.} = -\frac{G_{T.D.}}{2} + \sqrt{\frac{{G_{T.D.}}^2}{4} + 2\Omega_e E_{0.dyn.}\frac{M_s - \aleph_{stop.}}{\Re}\frac{\Lambda \pm \sqrt{\Lambda^2 - \Phi}}{\mathrm{P}}\left(t - e^{-\frac{\Re}{\Im_{stop.}}t}\right)}, \ N.$$

5). We shall determine the value of the change in the static belt load for the time from $t=t_{star.}$ *till* $t=t_{len.ch.}$ *(during the overclocking-length changing stage)*

$$S_{st.accel.}^{stop.} = \frac{\Omega_l l_{3-6}\left(2\mathrm{P} - \Lambda + \sqrt{\Lambda^2 - \Phi}\right)\left(\Omega_e l_{3-6} + G_{T.D}\right)}{\left(\Lambda + \sqrt{\Lambda^2 - \Phi}\right)\left(2\Omega_e l_{3-6} + \Omega_l l_{3-6} + G_{T.D.}\right) - 2\mathrm{P}\Omega_l l_{3-6}}, N.$$

6). We shall determine the value of the change in the dynamic belt load for the time from t=0 till $t=t_{star.}$ (during the starting stage)

$$S_{dyn.star.}^{stop.} = q_b \cdot V_{e.stop.} \sqrt{E_{0.dyn.} j_{e.stop.}^{star.} / \left(q_b j_{e.stop.}^{star.} + S_{st.stop.}^{star.} / l_{3-6}\right)},\ N.$$

where $E_{0.dyn.}$ – aggregate dynamic stiffness of the belt, (*N*); q_b – belt mass per unit length, (*kg/m*).

7). We shall determine the value of the change in the dynamic belt load for the time from $t = t_{star.}$ till $t = t_{len.ch.}$ (during the overclocking-length changing stage)

$$S_{dyn.stop.}^{over.} = q_b \cdot V_{e.stop.} \sqrt{E_{0.dyn.} j_{e.stop.}^{over.} / \left(q_b j_{n.stop.}^{over.} + S_{st.stop.}^{over.} / l_{3-6}\right)},\ N.$$

8). We shall determine the value of the change in the belt tension on the mobile station drum

$$S_{6stop.} = S_{6I}^{stop.} + S_{st.stop.}^{star.} + S_{st.stop.}^{over.} + S_{dyn.stop.}^{star.} + S_{dyn.stop.}^{over.}, N.$$

II. The calculation methodology for the belt load during the conveyor extension with the working drive

1). We shall determine the speed $V_{s.work.}$ and the acceleration $j_{s.work.}$ of the mobile station

$$V_{s.work.} = \left(M_s - \aleph_{work.}\right)\left[1 - \exp\left(-\Re \cdot t / \Im_{work.}\right)\right] / \Re,\ m/s;$$

$$j_{s.work.} = \exp\left(-\Re \cdot t / \Im_{work.}\right)\left(M_s - \aleph_{work.}\right) / \Im_{work.},\ m/s^2;$$

$$\Re = 2\beta_{el.mot.} / \left(R_{ast.} i_{rum.gear.}\right),\ N/s;$$

$$\Im_{work.} = 2\left(J_{r.el.mot.} + J_{1.gear.wh.} + J_{2.gear.wh.} i_{rum.gear.}\right) / \left(R_{ast.}^2 i_{rum.gear.}^2\right) + R_{ast.} i_{rum.gear.} (m_{hea.mach.} + m_{T.D.} + m_s + m_{red.dr.con.} + m_{drum.} + \Omega_l l_{(7-8)} / g + \Omega_e l_{(9-6)} / g) / 2,\ kg \cdot m;$$

$$\aleph_{work.} = \frac{R_{ast.} i_{rum.gear.}}{2}\left[\Omega_l l_{(7-8)} + \Omega_e l_{(9-6)} + g\left(m_{T.D.} + m_{hea.mach.} + m_{red.dr.con.} + m_{drum.} + m_s\right)\right],\ N \cdot m.$$

2). We shall determine the speed of a laden and empty conveyor arms while changing the transportation length

$$V_{l.work.} = V_{Ib} - V_{s.work.},\ m/s;$$

$$V_{e.work.} = V_{Ib} - V_{s.work.},\ m/s.$$

where V_{Ib} - the speed of the belt movement created by the conveyor drive, (*m/s*).

3). We shall determine the value of the change in the belt static load while changing the transportation length

$$S_{st.}^{work.} = \left(R + \sqrt{R^2 + \varPi}\right) / \left[4V_{e.work.}\left(V_{l.work.} - V_{st.work.}\right)\right],\ N;$$

$$R = V_{s.work.}\left[2V_{e.work.}\left(\Omega_e l_{3-6} + G_{T.D.} / 2\right) + V_{s.work.}\ \Omega_{l.} l_{3-6}\right],\ N \cdot m^2/s^2;$$

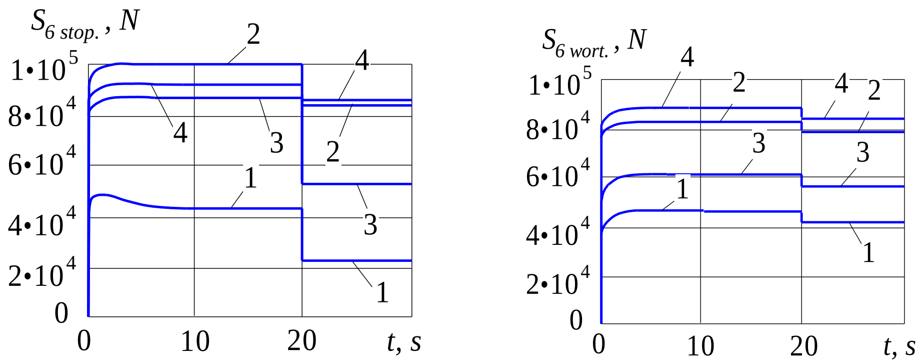
$$\varPi = 8V_{s.work.}^2 V_{e.work.} \Omega_{l.}\left(V_{l.work.} - V_{s.work.}\right)\left(\Omega_e l_{3-6}^2 + G_{T.D.} l_{3-6}\right),\ N^2 m^4/s^4.$$

4). We shall determine the value of the change in the belt dynamic load (during the overclocking-length changing stage)

$$S_{dyn.work.} = q_b \cdot V_{s.work.} \sqrt{E_{0.dyn.} j_{s.work.} / \left(q_b j_{s.work.} + S_{st.work.} / l_{3-6}\right)},\ N.$$

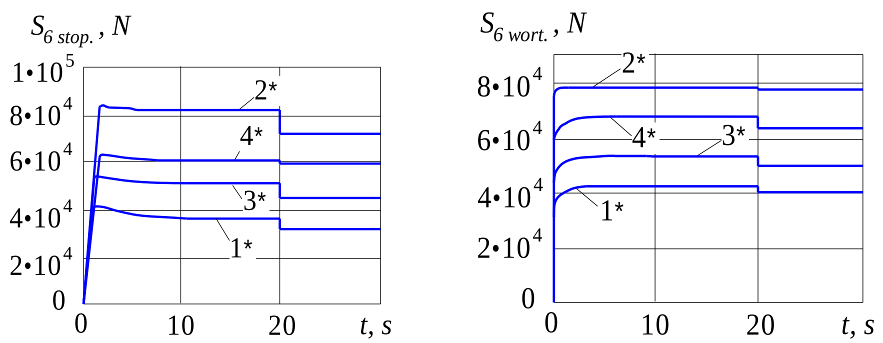
5). We shall determine the value of the change in the belt tension on the mobile station drum while changing the transportation length

$$S_{6work.} = S_{6I}^{work.} + S_{st.work.} + S_{dyn.work.},\ N.$$



***a*) *b*)**

Fig. 5. The graphs of the change in the belt tension on the mobile station drum while changing the transportation: *a*) with the stopped conveyor drive, *b*) with the working conveyor drive



***a*) *b*)**

Fig. 6. The graphs of the change in the belt tension on the mobile station drum while changing the transportation: *a*) with the stopped conveyor drive, *b*) with the working conveyor drive

In the Mathcad software, the graphs of the change of the belt strains occurring on the drum of the belt conveyor mobile station while changing the transportation length of a tubular conveyor with the running and stopped drive were constructed (Fig. 5, Fig. 6)
(tube diameter $D_{tube} = 0{,}3\ m$, $m_{drum.} = 100\ kg$, $m_{hea.mach.} = 35000\ kg$, $D_{ast.} = 1{,}0\ m$, $J_{1.gear.wh.} = 0{,}01\ kg{\cdot}m^2$, $J_{2.gear.wh.} = 25\ kg{\cdot}m^2$, $i_{rum.gear.} = 0{,}0064$, $\beta_{el.mot.} = 2$, $V_{Ib}^{work.} = 1{,}6\ m/s$, $l_{7-8} = 800\ m$, $M_s = 1000\ N{\cdot}m$, $E_{0.dyn.} = 26000000\ N$) for cases, when: 1 - $\beta = 0^0$, $l_{(3-6)} = 835\ m$; 2 - $\beta = 4^0$, $l_{(3-6)} = 835\ m$; 3 - $\beta = 7^0$, $l_{(3-6)} = 835\ m$; 4 - $\beta = 15^0$, $l_{(3-6)} = 835\ m$; 1* - $\beta = 0^0$, $l_{(3-6)} = 200\ m$; 2* - $\beta = 4^0$, $l_{(3-6)} = 200\ m$; 3* - $\beta = 7^0$, , $l_{(3-6)} = 200\ m$; 4* - $\beta = 15^0$, , $l_{(3-6)} = 200\ m$.

Conclusions

1. During the extension of the conveyor, there occurs an increase in belt load on the mobile station drum due to an increase in the static and dynamic tension of the belt.
2. When the transportation length of a conveyor is changed with the stopped drive, there are the starting and belt acceleration phases; when the transporting length is changed with the working drive, only the acceleration phase is the case.
3. The change in the belt static tension on the drum of the conveyor mobile station with the working drive depends on the speed of the mobile station and the belt speed that is created by the conveyor drive, as well as on the parameters and operating conditions.
4. The change in the belt static tension on the drum of the conveyor mobile station with the stopped drive depends on the parameters of a conveyor and a running gear moving the mobile station.
5. The increase in the belt static tension on the mobile station drum during the conveyor extension lasts as long as the transportation length change occurs.

6. The belt dynamic load during the transportation length change depends on the mass per unit length of a conveyor arm, belt speed and acceleration. The more the change in the belt static load is, the less the dynamic load is, the more the mobile station acceleration is, the more the belt dynamic load is.
7. For the slight angles in the conveyor setting, the change in the belt tension on the mobile station drum of the extending conveyor with the stopped drive is more, than for the extending conveyor with the working drive. The occurring changes in the belt tension depend considerably on the parameters of a drive moving the station and belt stiffness.
8. With increasing the angle in the conveyor setting, the change in the belt tension on the mobile station drum of the extending conveyor with the stopped drive may be less, than during the extension of a conveyor with the working drive.
9. The analysis of the occurring increases in the belt tension obtained experimentally and theoretically shows, with a slight angle in the conveyor setting the transportation length should be changed with the working drive.

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