MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF KAZAKHSTAN

School of Industrial Automation and Digitalization
Department of Industrial Engineering

Made by: Kuanyshev Kanat

CAD/CAE conveyor simulation for flexible production system

DIPLOMA WORK

Specialty 5B071200 – Mechanical Engineering

Almaty 2020

MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF KAZAKHSTAN

School of Industrial Automation and Digitalization
Department of Industrial Engineering

APPROVED FOR DEFENSE

Head of the Industrial Engineering Department, PhD
___________Arymbekov B.S.
“____”______________2020

DIPLOMA WORK

Topic: " CAD/CAE conveyor simulation for flexible production system"

5B071200-Mechanical Engineering

Performed by Kuanyshev Kanat Serikovich

Reviewer
____
____
_________2020

Scientific adviser
Candidate of Technical Sciences,
Associate Professor "_____"
______________Isametova M.E "
"_____" _________2020

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TASK
for completing the diploma work

For student: Kuanyshev Kanat Serikovich
Topic: " CAD/CAE conveyor simulation for flexible production system "
Approved *by the order of university rector №762-b from "27" January 2020*
Deadline for completion the work *"24" May 2020*
Initial data for the diploma project: Basic information about conveyors for flexible production system
Summary of the diploma work:

a) *Modern designs and methods for designing special belt conveyors;*
b) *Simulation of conveyor dynamics with suspended load-carrying belt and distributed drive;*
c) *Optimal design of steel structure of stationary conveyor with suspended load-carrying belt in software complex NX;*

List of graphic material: Graphical representations of details of conveyors
Recommended main literature:

1. Alexandrov, A.V. Strength of materials / A.V. Alexandrov, V.D. Potapov, B.P. Derzhavin. - M.: Vyssh. shk., 2004. - 560 pages.
2. Lagerev, A.V. Conveyors with suspended load-carrying belt - innovative type of continuous transport machines/A.V. Lagerev, V.P. Dunaev//Directory. Engineering Magazine. - 2009. - № 10. - 9-14p.

3. Boslovyak, P.V. Optimal design of steel structure of conveyor with suspended belt in software complex NX/ P.V. Boslovyak, A.V. Lagerev//Materials of the XVIII Moscow International Inter-University. scientific техн. конф. Students, postgraduate students and young scientists "Lift-transport, construction, road, travel Machines and robotics complexes. "- 2014. - Ч.1. - 14-17p.
4. Antonyak, E. Theoretical research and design New generation belt conveyors/E. Antonyak//Mountain information and analytical bulletin. - 2003. - № 10. - 154-157p.
5. Lagerev, A.V. Simulating the stressed-state of the conveyor belt with suspended belt in the area of intermediate unloading/A.V. Lagerev, E.M. Selyanin//Journal of the Bryansk State University. - 2015. - № 1. - 359- 65p.
6. Lagerev, A.V. RU Patent No. 153945 for Utility Model "Drive Suspension exact conveyor with suspended belt "/A.V. Lagerev, E.N. Tolkachev, K.A. Goncharov, D.Y. Kuleshov//Scientific and Technical Journal of the Bryansk State University. - 2015. - No. 1. – Page 77-78. URL: http://ntv-brgu. ru/wp-content/arhiv/ 2015-N1/2015-01-13.pdf.

THE SCHEDULE

For the diploma work preparation

Name of sections, list of issues being developed	Submission deadlines to the scientific adviser	Notes
General information about conveyors	20.02.2020	Task completed
Mathematical modeling of conveyor with suspended load-carrying belt and distributed drive	15.03.2020	Task completed
Usage of CAD/CAE system NX	30.04.2020	Task completed
Calculations of conveyors with suspended load carrying belt in software complex NX	25.04.2020	Task completed

Signatures

Of consultants and standard controller for the completed diploma work, indicating the relevant sections of the work (project).

The section titles	Consultant name (academic degree, title)	Date	Signature
Main part	Candidate of Technical Sciences,Isametova M.E	25.04.2020	
Normcontrol	Candidate of Technical Sciences,Isametova M.E	15.05.2020	

Scientific adviser _____________ Isametova M.E

The task was completed by student: ___________ Kuanyshev K.S.

Date: “15” May 2020

ANNOTATION

Conveyor transport is an integral part of the process of industrial enterprises: it regulates the pace production, ensures its uniformity, contributes to improvement of work productivity quality, effectively solves issues of complex mechanization and automation of transport and technological processes.

In the diploma work, a wide range of issues related to various aspects of the problem of improving the quality and efficiency of operation of conveyors, especially with a suspended load-carrying belt and various types of drive, such as - concentrated and distributed. Mathematical models of dynamic processes arising during operation of conveyors with hinged load-carrying belt and distributed drive are presented.

Method of rational design of bearing metal structures of stationary conveyors with hinged load-carrying belt and concentrated drive is considered. Results of practical implementation of the above method in the software complex NX are presented, as well as results of comparative analysis of its efficiency.The results of theoretical studies of technical data of conveyors with hinged load-carrying belt, aimed at assessment of impact of structural and mode data on their dynamics and optimization of metal structure, are presented. Technical conclusions on improvement of assembly flow system with hinged belt and distributed drive are proposed

АҢДАТПА

Конвейерлік көлік - бұл өнеркәсіптік кәсіпорындардың технологиялық процесінің ажырамас бөлігі: ол қарқыны реттейді, оның ырғағын қамтамасыз етеді, еңбек өнімділігінің сапасын арттырады, көліктік және технологиялық процестерді кешенді механикаландыру және автоматтандыру мәселелерін тиімді шешеді.

Дипломдық жұмыста конвейерлердің жұмысының сапасы мен тиімділігін жоғарылату мәселесінің әртүрлі аспектілеріне қатысты мәселелер қарастырылған, атап айтсақ, шоғырланған және таратылатын аспалы лента-лармен және әртүрлі жетектермен. Жүктелген таспа және үлестіргіш жетегі бар конвейерлерді пайдалану кезінде пайда болатын динамикалық процестердің математикалық модельдері келтірілген.

Бекітілген жүк таспасы мен концентрацияланған жетегі бар стационарлық конвейерлердің мойынтірек металл конструкцияларын ұтымды жобалау әдісі қарастырылған. NX бағдарламалық пакетінде осы техниканы практикалық қолдану нәтижелері, сонымен қатар оның тиімділігін салыстырмалы талдау нәтижелері келтірілген. Монтаждалған таспамен және үлестіргіш жетегімен құрастыру ағынының жүйесін жақсарту туралы техникалық қорытынды ұсынылады.

АННОТАЦИЯ

Конвейерный транспорт составляет неотъемлемую часть технологического процесса промышленных предприятий: регулирует темп производства, обеспечивает его ритмичность, способствует повышению качества производительности труда, эффективно решает вопросы комплексной механизации и автоматизации транспортно-технологических процессов.

В дипломной работе, рассмотрен широкий спектр вопросов, связанных с различными аспектами проблемы повышения качества и эффективности эксплуатации конвейеров, в особенности с подвесной грузонесущей лентой и различными видами привода, такие как – сосредоточенный и распределенный. Представлены математические модели динамических процессов, возникающих при работе конвейеров с навесной грузонесущей лентой и распределенным приводом. Рассмотрен способ рационального проектирования

несущих металлоконструкций стационарных конвейеров с навесной грузонесущей лентой и сосредоточенным приводом.

Представлены результаты практической реализации указанной методики в программном комплексе NX, а также результаты сравнительного анализа ее эффективности. Предложены технические заключения по совершенствованию системы сборочного потока с навесной лентой и распределенным приводом.

CONTENT

INTRODUCTION

Continuous transport machines reduce the use of physical labour, reduce labour intensity and time for carrying out lifting and transportation, loading and unloading and storage works in industry, construction, agriculture, food production and other industries. The main advantage of this type of continuous transport over periodic machines is the movement of cargo by continuous flow without interruptions for loading and unloading. The domestic and foreign practice of using traditional belt conveyors shows that they have significant difficult-to-cure disadvantages, leading to a number of undesirable phenomena during operation.

1. Transverse shift of the conveyor belt in motion caused by skewing of the roller supports, deflection of the plate from the conveyor axis, asymmetric distribution of tension over the width of the belt, leads not only to wear and rush of the sides of the belt due to contact with the posts of the steel structure of the conveyor, but also, in some cases, to fire.

2. Unstable transverse movement of conveyor belt together with its vertical oscillations due to inevitable slack in spans between fixed roller supports during operation leads to dust, crushing and unloading of transported material.

3. The load leakage occurring during belt movement causes jamming of the lower run of the conveyor as well as jamming of the fixed roller supports as a result of sticking of the material and occurrence of impacts.

4. Increasing belt tension to reduce sliding boom and provide traction force by friction drive causes fatigue wear of belt and shortening its service life.

5. Sufficiently high resistance to movement of conveyor belt on fixed support roller supports installed along conveyor route due to belt sagging, bending of deflecting drums, friction of its rubber strip against rollers and vertical steel struts lead to increased energy consumption of freight transportation.

Therefore, the task of creating new types of belt conveyors without the disadvantages of conventional conveyors is urgent. A belt conveyor with a suspended belt and a distributed drive has a number of fundamental advantages:

• The possibility of manufacturing conveyors of virtually any length without the need to install metal-intensive and bulky intermediate drive stations;

• Highly adaptable to possible changes in operating conditions, such as changes in conveyor length or productivity;

• Increased reliability indicators, including complex indicators (availability, technical use factors, etc.), as the drive suspensions implement the function of multiple redundancy of the traction force of the conveyor belt drive;

• Ability to control conveyor capacity by changing belt speed with drive hangers;

• Complete unification of drive elements allows for short-term replacement of the disconnected suspension and reduced conveyor downtime.

Continuous transport machines with suspended carrier tape have no analogues abroad. Therefore, the results of scientific research of this constructive type of conveyor transport are unique for both domestic and foreign engineering science and practice.

1 Modern designs and methods for designing special belt conveyors

1.1 Structures, features of operation and operation tape conveyors

Traditional belt conveyors are the primary and most common means of continuously transporting various bulk and piece cargoes in industry, construction, agriculture, food production and other industries [1].

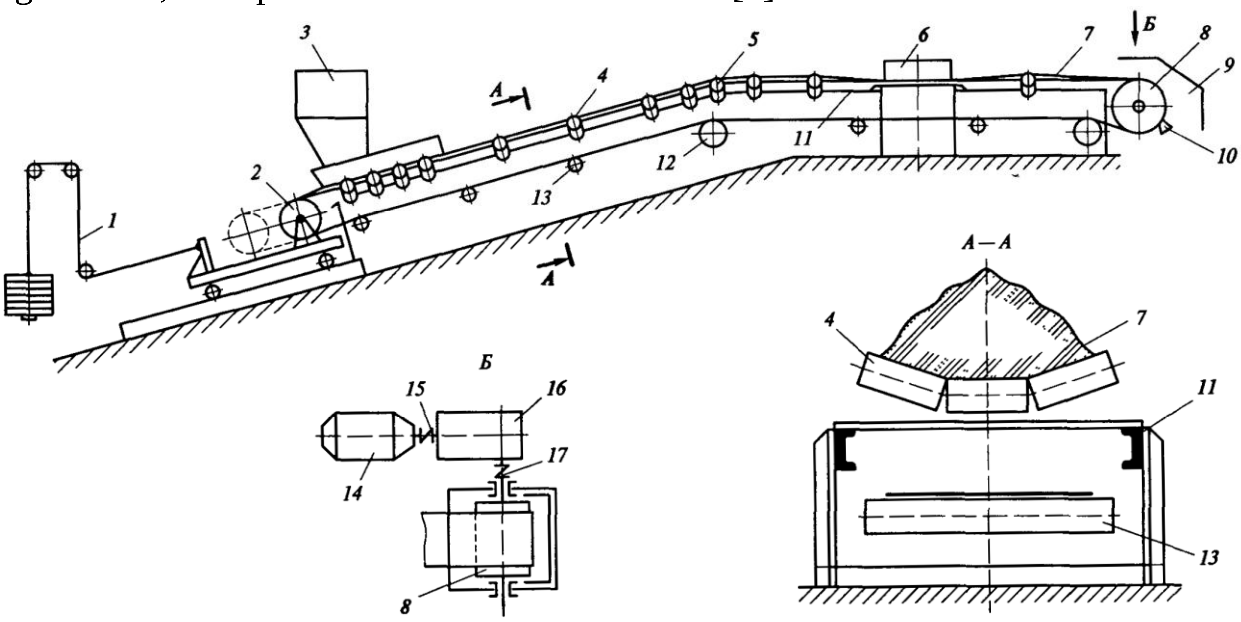


Figure 1- Scheme of the tape conveyor

The bearing and pulling element of the general purpose belt conveyor (Figure 1) is an endless flexible belt 7 supported by the upper (load-carrying) and lower (blank) legs on the roller supports 4, 13 and enveloping at the conveyor ends the drive drum 8 and tension drum 2. In short conveyors, often used to move piece loads, the working run of the belt can slide over a wooden or metal flooring. Motion is transmitted by friction method from drive drum. The necessary initial tension on the running-off branch of the belt is created by a tension drum by means of a load or screw type tensioner 1. The bulk weight is fed to the belt via a hopper 3,mounted at the beginning of the conveyor at the end tension drum 2.

Transported load is transferred to upper branch of belt, and lower branch - back. It is also possible to transport cargoes simultaneously along the upper and lower branches of the belt in different directions. The discharge of the belt may be a final or intermediate one using a movable discharge trolley or stationary ploughshare 6. The direction of the discharge load flow is provided by a discharge box 9 having one or two funnels. Rotating brushes or fixed scraper 10 are mounted to clean the working side of the belt of remaining particles [1].

Belt conveyor drive consists of drum 8, electric motor 14, reduction gear 16 and couplings 15, 17. Roller batteries 5 forming smooth band bending or deflecting drums 12 are installed on rotating sections of route branches.
All conveyor elements are mounted on metal structures 11.

The metal structure is attached to the foundation or support parts of the building.

Metal structures of general purpose belt conveyors include support structures (machine beds), shelters and fences of individual parts of the conveyor. Conveyor support structures consist of four main parts: drive (head) drum supports; Frames of the driving mechanism; Support structure of the middle part of the conveyor (stack), consisting of sections and posts, as well as support of the tensioner. Next, only auxiliary metal structures intended for use in various industries in temperate and tropical climates will be considered. They can also be used in explosive and reactive environments and other special conditions.

The ease of construction of belt conveyors, as well as the ability to provide high productivity and technical and economic efficiency in large cargo flows over the years, have identified them as one of the main means of continuous transport in mining, metallurgical, construction, chemical and other industries [1].

1.2 Technical Solutions for Improvement of Conveyor Design with Suspended Belt and Distributed Drive

This monograph describes an improved suspended belt and distributed drive conveyor design (Figure 2) for transporting bulk loads that do not have self-ignition and explosion hazard properties. Conveyor comprises bearing and idle runs, loading and unloading points, as well as rotary and transition sections (trough forming and pressing) [2].

Components of the structure, two types of suspension, current-conducting bogies and bearing belt become composite.

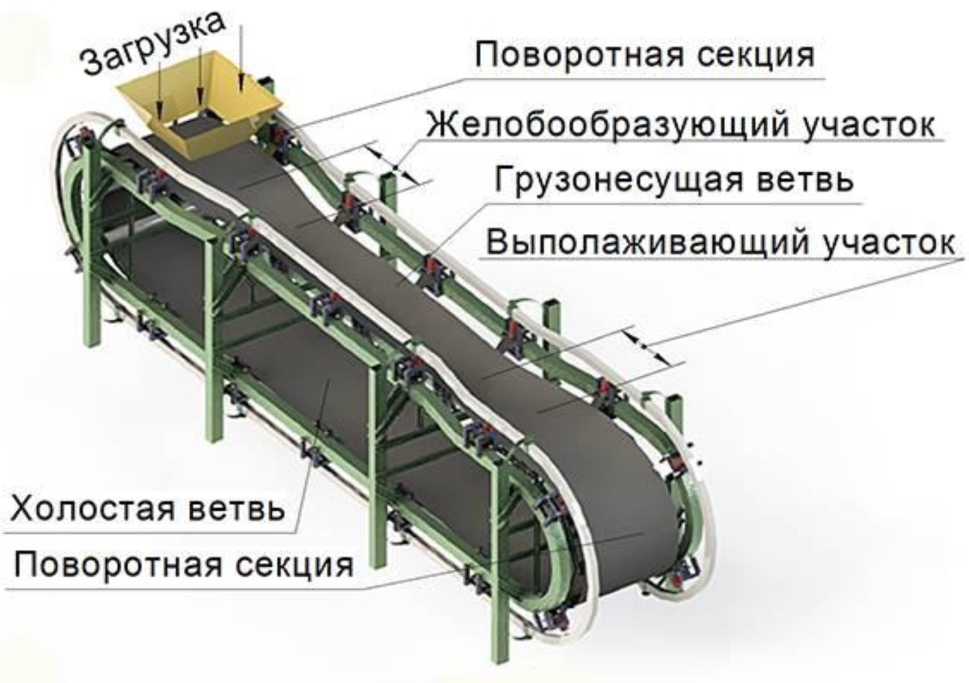


Figure 2- General view of conveyor with suspended belt and distributed drive

Getting to be transport 1 (Figure 3) may be a unbending metal structure shaped by belts and posts with rolling guides 7 and trolleys 8 settled on them. Rolling guides on the cargo department are near, whereas on sit out of gear and conclusion turning segments the span between them is expanded, and closing of the direct track takes put in move areas [2].

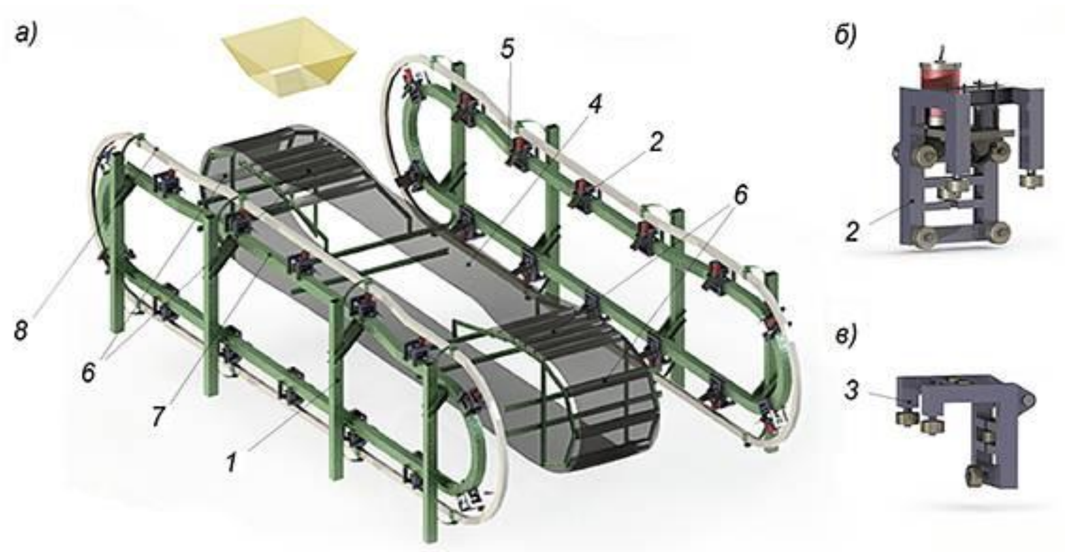


Figure 3-Conveyor design with suspended belt and distributed drive: a - conveyor layout diagram; B is a general view of the drive pendants; C - general view of non-guide suspension

Suspensions holding in suspended position by implies of connection units 5 unending belt 4 closed along transport post and moving at the side it along rolling guides, depending on reason, are displayed in two sorts - drive 2 and drive 3 (or drive and non-drive). Orchestrated in bunches of one driving and a few driven suspensions symmetrical relative to longitudinal hub of transport are orchestrated discretely with rise to pitch along rolling guides. Transport has no metal-consuming and bulky drive and tensioning stations, but furthermore it is prepared with roller batteries 6 supporting belt, introduced at conclusion turning segments and at stacking station. This arrangement avoids damaging distortions of the trough belt on the swivel segment and makes a difference to decrease the stack on its sides amid fabricate. Operation of transport with suspended belt and dispersed drive is performed as takes after. Electric current provided to current-conducting intruders through current collectors drives electric motors-reducers of driving suspensions. Drive rollers squeezed by weight gadgets to direct tracks turning along side yield shafts of drives cause drive suspensions to touch from put. Development of drive suspensions through connection units is to begin with exchanged to belt and after that associated with it to conducted suspensions. At the same time amid development the coming about abundance footing drive of underloaded motors is redistributed by implies of belt and compensates for need of pushed of over-burden motors. Moving along the rolling guides of the move areas, the suspensions frame a belt profile: at the starting of the bearing department, closing, shaping a plate, and at the conclusion, veering on the sides, the belt is made [2].

In the folded state, the belt overcomes the end turning sections, on which the fixed roller supports are further supported, and the suspensions, turning in the direction of movement, are supported by opposite rollers. At further movement along idle stroke, pressure devices of drive suspensions provide required pressing of drive rollers to rolling guide.

The design of drive suspensions is based on the principle of sequentially reducing the number of degrees of freedom to the required number (most often one) due to the design and tasks of a particular conveyor. In practice, compliance with the principle conditions is achieved by the installation of additional rollers, which allows to eliminate skew of suspensions during movement. Deviation from position of stable balance of suspensions not only reduces efficiency of traction force transmission due to creation of additional resistance to movement from sliding friction of beveled rollers, but also leads to jamming.

The shape, size and material of the rollers largely determine the ease of movement of the suspensions, as well as the durability of the tracks and the rollers themselves. Flat surfaces of rolling due to rectangular profile of guide take cylindrical shape of rim of suspended rollers, which is optimal in its general characteristics. However, in the case of tubular rolling guides, the rim shape of the suspension rollers must have a concave rolling surface.

а) б)

Figure 4- Conveyor drive suspension with suspended belt and distributed drive: a - general view; B - layout diagram

Drive suspension comprises of two components: bearing and squeezing areas. The base of the bearing portion may be a metal structure 1 within the shape of an open outline. Its profile features a shape comparable to the cross segment of the direct trajectory, However, it is drawn along one side. The pairwise arranged cantilever rollers 2 are generally oriented to each surface of the rail profile. For connection of element of conveyor belt fixation in metal structure of support section there are lugs with axle 3 arranged in them. Proposed section comprises frame 4 with reduction engine 5 secured thereon and pair of bearing supports 6. Power supply of drive from electric network is provided by current collector fixed on it. Drive roller 7 with its rolling surface made from material with high coefficient of friction is arranged on reduction motor shaft between thrust bearing supports. Pressing part of driving suspension connected to support section is equipped with pressing device 8 with possibility of adjustment [3].

2 Simulation of conveyor dynamics with suspended load-carrying belt and distributed drive

The method of planning cutting edge specialized frameworks requires fathoming a wide run of logical and specialized issues, including:
- Justification for the ought to make a modern machine;
- Logical and specialized investigate on models and definition of fundamental parameters;
- Advancement of plan documentation;
- Fabricating, testing and wrapping up of the test pieces. The mindful organize, which in numerous ways decides the operability, specialized level, quality and effectiveness of the planned machine, is the arrange of logical inquire about and its most effective apparatus - scientific modeling. It permits to anticipate in early stages the most properties of the made machine, to carry out computer tests reenacting modes of operation, as well as to think about and decide levelheaded and ideal plan parameters. This chapter portrays the created scientific demonstrate for computer hardware reenactment of transport flow with suspended load-carrying belt and dispersed drive.

Scientific show of transport with suspended belt and disseminated drive in common, which permits to calculate fundamental energetic characteristics and is utilized to decide levelheaded plan parameters of transport [4].

2.1. Mathematical model of conveyor with suspended load-carrying belt and distributed drive

Analysis and evaluation of dynamic processes taking place during operation of the conveyor with suspended belt and distributed drive in order to select rational parameters of the main elements and nodes at the design stage should be carried out on the basis of mathematical modeling. Earlier, the authors developed models of movement of a discrete section (groups of hangers consisting of one drive and several non-drive hangers) and the whole conveyor. However, in view of the rather unreliable friction method used to transmit the thrust by the drive rollers of the drive suspensions, it is important to implement in the mathematical model the possible rolling conditions of the drive rollers during the operation of the conveyor. Since the movement of the drive rollers determines the efficiency of the conveyor section [5].

The design diagram of the conveyor (Figure 5) is based on the following assumptions:

1) conveyor with suspended belt and distributed drive is modeled by system of connected elastic-viscous links of discrete masses;
2) each discrete mass characterizes suspension with band section and mass connected to it and represents roller with forces and masses reduced to its center;

3) neglect of longitudinal gap of belt under action of load and its transverse oscillations leading to additional resistances;
4) suspension rollers are absolutely rigid, undeformed elements;
5) volume weight is uniformly distributed between suspensions;
6) suspensions on different guides are arranged absolutely symmetrically and have equal movements, speeds and accelerations.

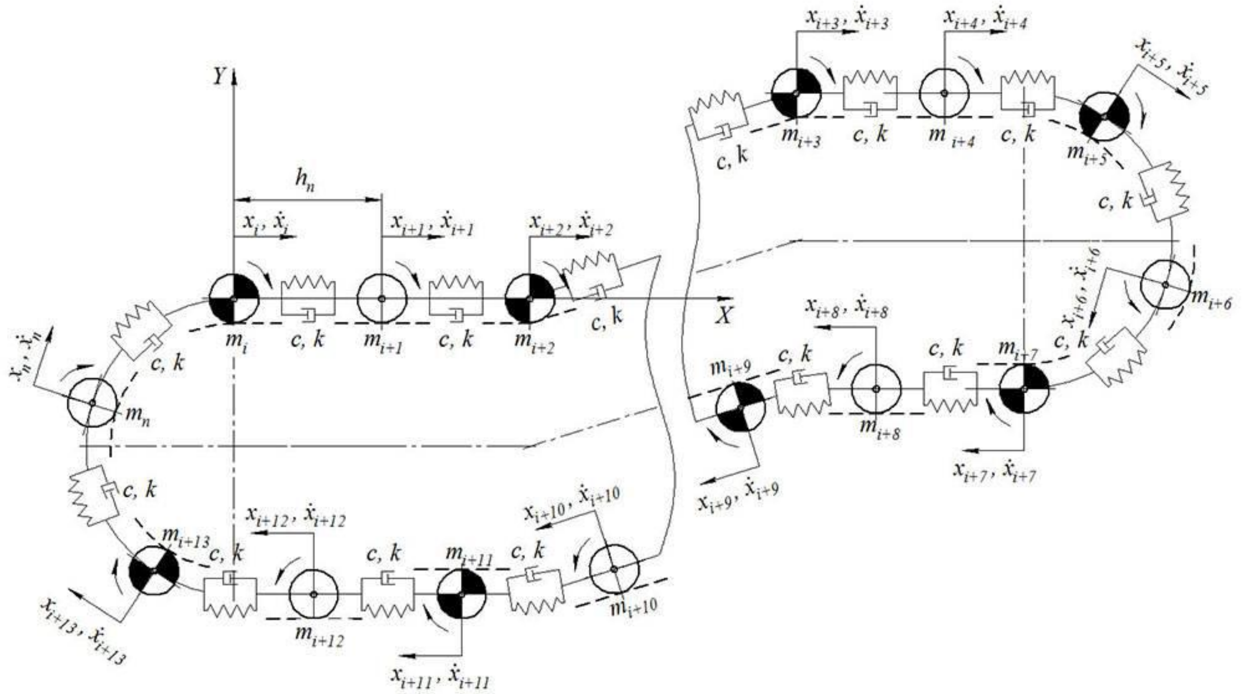


Figure5- Design diagram of conveyor with suspended belt and distributed drive

Dynamics of conveyor with suspended belt and distributed drive are described by ratios obtained on the basis of the Dalamber principle. The connections are replaced by their reactions and applied together with inertial forces and inertial moments to each element of the system (Figure 6). Equations of driving roller dynamics (Figure 6, a) of driving suspension in the considered mathematical model have the form

$$\begin{cases} m_{ni}\ddot{x}_{ni} = F_{cц_i} + \left(G_n + T_i \sin\beta_i\right)\sin\alpha_i + k_i\left(\dot{x}_{i-1} - 2\dot{x}_i + \dot{x}_{i+1}\right) + c\left(x_{i-1} - 2x_i + x_{i+1}\right); \\ m_{ni}\ddot{y}_{ni} = N_{np_i} - G''_n \cos\alpha_i - F_{np}; \\ J_{on_i}\ddot{\varphi}_{ni} = M_{кp_i} - F_{cц_i} r_{np} - N_{np_i} f_{np} - M^{np}_{\Sigma i}, \end{cases} \tag{2.1}$$

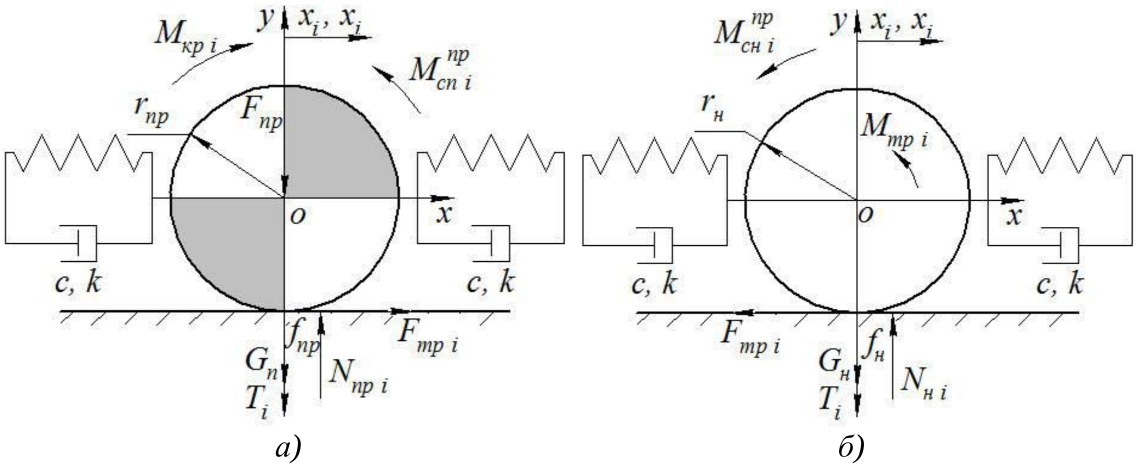


Figure 6- Settlement schemes of rollers: a – driving;; б – single

where $\ddot{x_n}$, $\ddot{y_n}$ – linear accelerations of the driving roller in the direction of the respective axes; $\ddot{\varphi_n}$ – angular acceleration of drive roller relative to rotation axis; $\dot{x}$, x –Speed and movement of suspension rollers; m_n , J_{on} –Reduced mass and moment of inertia of the drive suspension; G_n,G''_n – Gravity of the drive suspension and the pressure section of the drive suspension; T – force from weight of cargo and belt acting from the side of suspension attachment with belt; F_{np} – the force acting on the driving roller from the side of the pressing device; N_{np} – the normal reaction force of the support surface; $F_{\text{сц}}$ – the force of engagement of the driving roller with the bearing surface; $M_{\text{кр}}$ – torque of drive suspension gear motor; M_{Σ}^{np} – reduced moment of resistance to movement of drive suspension;
f_{np} – coefficient of rolling friction of drive roller with support surface; c – the reduced stiffness of the elastic element (tape); k – coefficient of damping element resistance; r_{np} – the outer radius of the drive roller; α – angle of suspension inclination in vertical plane; β – angle of tape sides inclination to horizon;
i – suspension sequence number;

Movement of driven roller of non-drive suspension (Figure 4, b) is described by the following differential relations [5]:

$$\begin{cases} m_{нi}\ddot{x}_{нi} = -F_{сц_i} + (G_н + T_i \sin\beta_i)\sin\alpha_i + k_i(\dot{x}_{i-1} - 2\dot{x}_i + \dot{x}_{i+1}) + c(x_{i-1} - 2x_i + x_{i+1}); \\ m_{нi}\ddot{y}_{нi} = N_{нi} - (G_н + T_i \sin\beta_i)\cos\gamma_i; \\ J_{онi}\ddot{\varphi}_{нi} = F_{сц_i} r_н - N_{нi}(f_н + \mu_{но} r_о) - M^{пр}_{\Sigma i}, \end{cases} \tag{2.2}$$

where $\ddot{x_{\text{н}}}$, $\ddot{y_{\text{н}}}$ – linear accelerations of the leading roller in the direction of the corresponding axes;
$\ddot{\varphi_n}$ – angular acceleration of the leading roller concerning a rotation axis;
$m_{\text{н}}$, $J_{o\text{н}}$ – the specified mass and the moment of inertia of a driving pendant;
$G_{\text{н}}$ – gravity of non-drive suspension;
$N_{\text{н}}$ – the normal reaction force of the support surface;
$F_{\text{сц}}$ – the force of engagement of the driving roller with the bearing surface;
M_{Σ}^{np} – reduced moment of resistance to movement of drive suspension;

$f_н$ – coefficient of rolling friction of driven roller with support surface;
$\mu_{НО}$ –the sliding friction coefficient in the roller axis;
$r_Н$ –the outer radius of the driven roller;
$r_о$ – the inner radius of the driven roller.

During the movement, the rollers do not break off from the support surface, therefore,

$$y_{п_i} = r_{пр} = const \text{ и } y_{н_i} = r_н = const \,, \qquad (2.3)$$

and, so and

$$\ddot{y}_{пi} = \ddot{y}_{нi} = 0 \,. \qquad (2.4)$$

Considering that the driven rollers of the hangers rotate without slip, the equation of kinematic connections is true:

$$\ddot{x}_{н_i} = \ddot{\varphi}_{н_i} r_н \,. \qquad (2.5)$$

Drive rollers of drive suspensions can move in one of possible rolling modes.

In case speed of roller contact point with fixed support of rolling guide exceeds zero

$$\dot{\varphi}_{п_i} r_{пр} - \dot{x}_{п_i} > 0 \,, \qquad (2.6)$$

towing of drive roller takes place. Friction force is defined as

$$F'_{сц_i} = \mu_{пр} N_{пр_i} = \mu_{пр}\left(G''_п \cos\alpha_i + F_{пр}\right), \qquad (2.7)$$

where $\mu_{пр}$ – the friction coefficient of sliding of the driving roller on the bearing surface.

If speed of roller contact point with fixed support of rolling guide is less than zero,

$$\dot{\varphi}_{пi} r_{пр} - \dot{x}_{пi} < 0 \,, \qquad (2.8)$$

suspension movement is accompanied by sliding of driving roller.

Friction force is equal:

$$F''_{сц_i} = -\mu_{пр} N_{пр_i} = -\mu_{пр}\left(G''_п \cos\alpha_i + F_{пр}\right). \qquad (2.9)$$

Otherwise, the point of contact of the roller with the bearing surface is fixed

$$\dot{\varphi}_{пi} r_{пр} - \dot{x}_{пi} = 0 \,, \qquad (2.10)$$

and there is a net rolling of the drive roller without slipping over the bearing surface. The friction force is determined from the kinematic connection equation by the expression [9]:

$$F_{cu_i} = \frac{1}{J_{o_i} + m_i r_{np}^2}\left[m_i r_{np}\left(M_{\kappa p_i} - M_{\Sigma}^{np} - \left(G''_n \cos\alpha_i + F_{np}\right)f_{np}\right) - J_{oi}\left(\left(G_n + T_i \sin\beta_i\right)\sin\alpha_i + \right.\right.$$
$$\left.\left. + k_i\left(\dot{x}_{i-1} - 2\dot{x}_i + \dot{x}_{i+1}\right) + c\left(x_{i-1} - 2x_i + x_{i+1}\right)\right)\right] \tag{2.11}$$

By converting the systems of suspension motion equations taking into account the possibility of sliding only the driving rollers of the model, we get:

- Acceleration of center of mass of non-drive roller of driven suspension

$$\ddot{x}_{\text{н}i} = \frac{r_\text{н}}{J_{o\text{н}i} + m_{\text{н}i} r_\text{н}^2}\left[-M_{\Sigma i}^{np} + r_\text{н}\left(\left(G_\text{н} + T_i \sin\beta_i\right)\sin\alpha_i + k_i\left(\dot{x}_{i-1} - 2\dot{x}_i + \dot{x}_{i+1}\right) + \right.\right.$$
$$\left.\left. + c\left(x_{i-1} - 2x_i + x_{i+1}\right)\right) - \left(f_\text{н} + \mu_{\text{н}o} r_\text{н}\right)\left(G_\text{н} + T_i \sin\beta_i\right)\cos\gamma_i\right] \tag{2.12}$$

- Acceleration of center of mass and angular acceleration of drive roller:

$$\begin{cases} \ddot{x}_{ni} = \dfrac{1}{m_{ni}}\left(F_{cu_i} + \left(G_n + T_i \sin\beta_i\right)\sin\alpha_i + k_i\left(\dot{x}_{i-1} - 2\dot{x}_i + \dot{x}_{i+1}\right) + c\left(x_{i-1} - 2x_i + x_{i+1}\right)\right); \\ \ddot{\varphi}_{ni} = \dfrac{1}{J_{oni}}\left(M_{\kappa p_i} - F_{cu_i} r_{np} - \left(G''_n \cos\alpha_i + F_{np}\right)f_{np} - M_{\Sigma i}^{np}\right) \end{cases} \tag{2.13}$$

The given equations characterize the dynamics of drive and non-drive suspensions. Dynamic behavior of conveyor with suspended belt and distributed drive is determined by solution of system of differential equations of first order, quantity of which depends on number and type of suspensions. The general view of the equation system is as follows:

$$
\begin{cases}
\dfrac{dx_1}{d\tau}=\dot{x}_1; \\
\dfrac{d\dot{x}_1}{d\tau}=\dfrac{1}{M_n(x_1+H_1)}\Big[F_{сц}(x_1,x_2,x_n,\dot{x}_1,\dot{x}_2,\dot{x}_n,\dot{\varphi}_1)+(G_П+Q_Л+Q_Г(x_1+H_1))\cdot\sin\alpha(x_1+H_1)- \\
-c\cdot(2x_1-x_2-x_n))-\left(2\xi\sqrt{M_n(x_1+H_1)}\right)\cdot(2\dot{x}_1-\dot{x}_2-\dot{x}_n)\Big]; \\
\dfrac{d\varphi_1}{d\tau}=\dot{\varphi}_1; \\
\dfrac{d\dot{\varphi}_1}{d\tau}=\dfrac{1}{J_n(x_1+H_1)}\Big[M_{кр}(\dot{\varphi}_1)-F_{сц}(x_1,x_2,x_n,\dot{x}_1,\dot{x}_2,\dot{x}_n,\dot{\varphi}_1)\cdot r_n-M_{ПРИВ1}(x_1+H_1)- \\
-f_1\cdot(G_{ПС}\cdot\cos\alpha(x_1+H_1)+F_{пр})\Big]; \\
\dfrac{dx_2}{d\tau}=\dot{x}_2; \\
\dfrac{d\dot{x}_2}{d\tau}=\dfrac{r}{J_{нп}(x_2+H_2)+M_{нп}(x_2+H_2)\cdot r^2}\Big[-M_{ПРИВ2}(x_2+H_2)+r\cdot\big[(G_Н+Q_Л+Q_Г(x_2+H_2))\cdot \\
\cdot\sin\gamma(x_2+H_2)-c\cdot(2x_2-x_3-x_1))-\left(2\xi\sqrt{M_n(x_2+H_2)}\right)\cdot(2\dot{x}_2-\dot{x}_3-\dot{x}_1)\big]- \\
-(f_2+r_0\cdot\mu_2)\cdot(G_Н+Q_Л+Q_Г(x_2+H_2))\cdot\cos\gamma(x_2+H_2)\Big]; \\
\ldots \\
\dfrac{dx_j}{d\tau}=\dot{x}_j; \\
\dfrac{d\dot{x}_j}{d\tau}=\dfrac{1}{M_n(x_j+H_j)}\Big[F_{сц}(x_j,x_{j+1},x_{j-1},\dot{x}_j,\dot{x}_{j+1},\dot{x}_{j-1},\dot{\varphi}_j)+(G_П+Q_Л+Q_Г(x_j+H_j))\cdot \\
\cdot\sin\alpha(x_j+H_j)-c\cdot(2x_j-x_{j+1}-x_{j-1}))-\left(2\xi\sqrt{M_n(x_j+H_j)}\right)\cdot(2\dot{x}_j-\dot{x}_{j+1}-\dot{x}_{j-1})\Big]; \\
\dfrac{d\varphi_j}{d\tau}=\dot{\varphi}_j; \\
\dfrac{d\dot{\varphi}_j}{d\tau}=\dfrac{1}{J_n(x_j+H_j)}\Big[M_{кр}(\dot{\varphi}_j)-F_{сц}(x_j,x_{j+1},x_{j-1},\dot{x}_j,\dot{x}_{j+1},\dot{x}_{j-1},\dot{\varphi}_j)\cdot r_n- \\
-M_{ПРИВ1}(x_j+H_j)-f_1\cdot(G_{ПС}\cdot\cos\alpha(x_j+H_j)+F_{пр})\Big]; \\
\ldots \\
\dfrac{dx_n}{d\tau}=\dot{x}_n; \\
\dfrac{d\dot{x}_n}{d\tau}=\dfrac{r}{J_{нп}(x_n+H_n)+M_{нп}(x_n+H_n)\cdot r^2}\Big[-M_{ПРИВ2}(x_n+H_n)+r\cdot\big[(G_Н+Q_Л+Q_Г(x_n+H_n))\cdot \\
\cdot\sin\gamma(x_n+H_n)-c\cdot(2x_n-x_1-x_{n-1}))-\left(2\xi\sqrt{M_n(x_n+H_n)}\right)\cdot(2\dot{x}_n-\dot{x}_1-\dot{x}_{n-1})\big]- \\
-(f_2+r_0\cdot\mu_2)\cdot(G_Н+Q_Л+Q_Г(x_n+H_n))\cdot\cos\gamma(x_n+H_n)\Big];
\end{cases}
$$

Where the coupling force of the drive roller of the drive suspension is determined by the viewing condition:

$$
F_{сц}(x_1,x_2,x_n,\dot{x}_1,\dot{x}_2,\dot{x}_n,\dot{\varphi}_1)=
\begin{cases}
\mu_1\cdot(G_{ПС}\cdot\cos\alpha(x_1+H_1)+F_{пр}) \quad \text{если} \quad x_1 r_n-\dot{x}_1>0; \\
-\mu_1\cdot(G_{ПС}\cdot\cos\alpha(x_1+H_1)+F_{пр}) \quad \text{если} \quad x_1 r_n-\dot{x}_1<0; \\
\dfrac{1}{J_n(x_1+H_1)+M_n(x_1+H_1)\cdot r_n^2}\Big[M_n(x_1+H_1)\cdot r_n\cdot(M_{кр}(\dot{\varphi}_1)- \\
-M_{ПРИВ1}(x_1+H_1)-f_1\cdot(G_{ПС}\cdot\cos\alpha(x_1+H_1)+F_{пр}))- \\
-J_n(x_1+H_1)\cdot((G_П+Q_Л+Q_Г(x_1+H_1))\cdot\sin\alpha(x_1+H_1)- \\
-c\cdot(2x_1-x_2-x_n)-\left(2\xi\sqrt{M_n(x_1+H_1)}\right)\cdot(2\dot{x}_1-\dot{x}_2-\dot{x}_n))\Big]
\end{cases}
\tag{2.14}
$$

The presented system of differential equations is solved by numerical integration according to Runge-Kutt method of 4 order [6].

3 Optimal design of steel structure of stationary conveyor with suspended load-carrying belt in software complex NX

The purpose of the optimum construction of the steel structure of a fixed conveyor with a suspended belt is to maximize the use of the stored safety margin of the structure. This is achieved by providing a metal structure having a minimum mass when performing structural, strength, deformation, corrosion and mounting constraints [6].

The steel structure of the suspended belt conveyor consists of four structural units (Figure 7), which in turn are divided into elements.

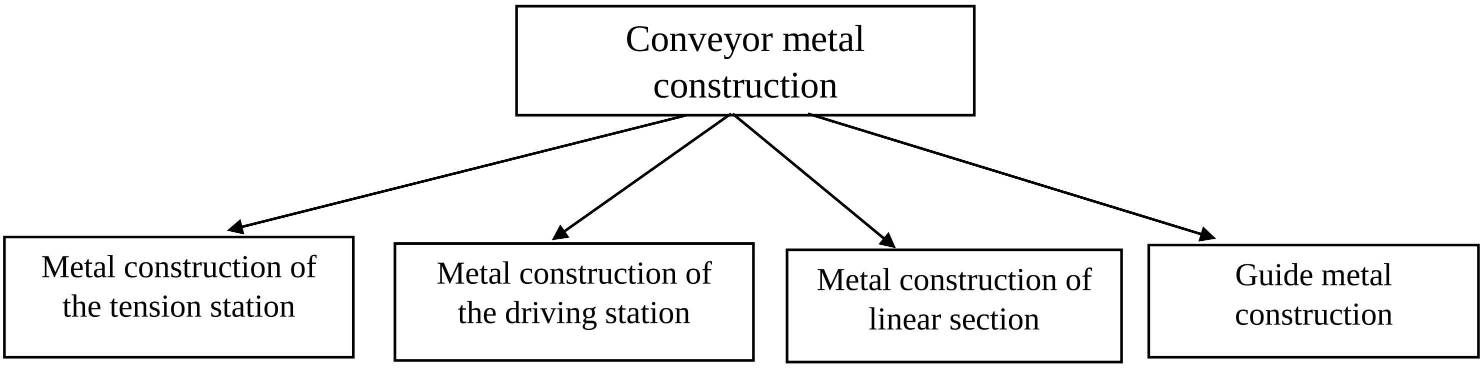
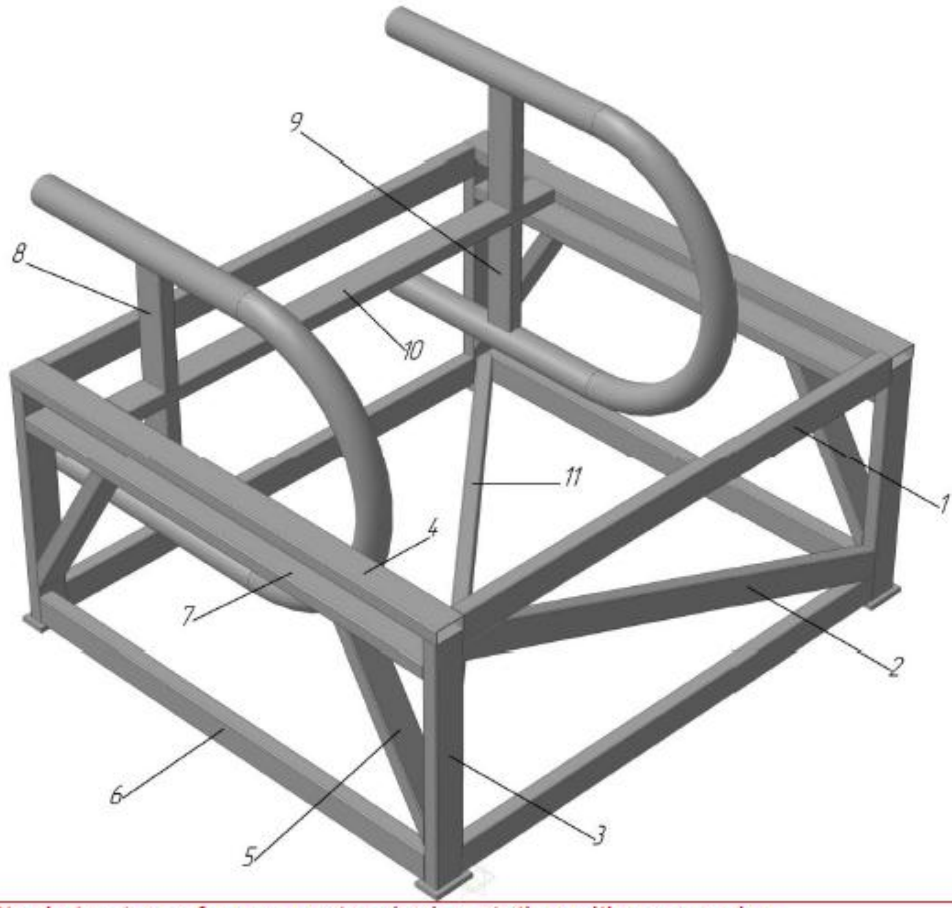


Figure 7-Conveyor metal construction

Structural diagram of the steel structure of the tensioning station.
Metal structures of the tensioning station (figure 8) consists of four main groups of rods:

- longitudinal (4,6,7);
- cross (1.10);
- vertical (3,8,9);
- braces (2,5,11).

Rods of each of these groups are rigidly connected to each other by welding. Clamps 2, 5, 11 are installed to make metal structure more rigid. Vertical posts 8 and 9 are attached to frame of metal structure of tension station, on which horizontal guides are installed. The transition section of the guide (from the load bearing to the idler) is usually made of a solid cross-sectional element, as there is an increased intensity of frictional wear of the outer surface of the guide from the side of the movable suspensions [6].



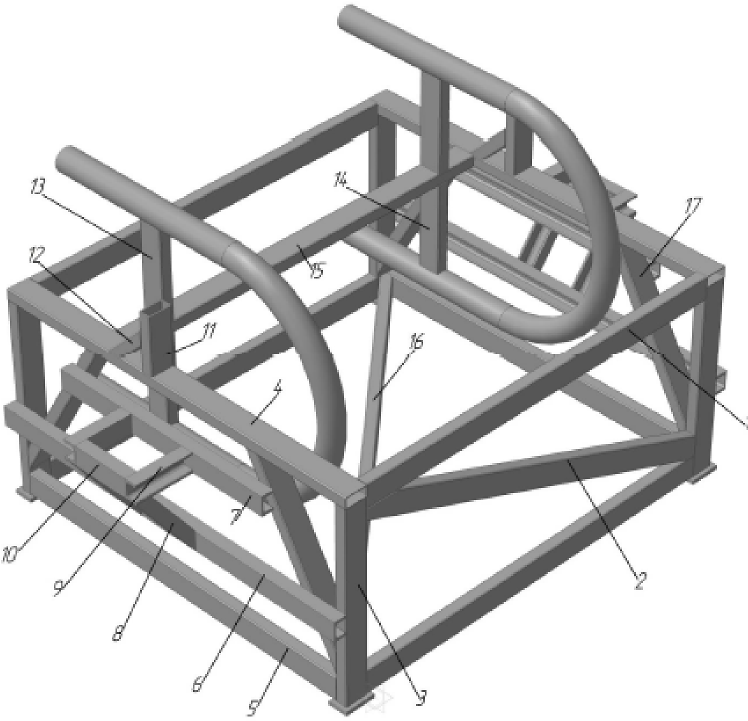
Steel structure of conveyor tensioning station with suspension
Tape: 1 - transverse rod; 2 – brace; 3 - vertical strut;
4 is a longitudinal rod; 5 – brace; 6, 7 - longitudinal rod;
8 - vertical strut of cargo branch; 9 - vertical stand of idle branch; 10 - transverse rod; 11 – brace

Figure 8- Structural diagram of the steel structure of the tensioning station.

Structural diagram of the metal structure of the drive station.
Metal structure of the drive station (fig. 9) consists of four main groups of rods:

- longitudinal (4,5,6,7,10);
- cross (1,9,15);
- vertical (3,11,13,14);
- braces (2,8,12,16,17).

The design of the drive station provides for the installation of two parallel operating drive mechanisms, since two less powerful mechanisms with the required traction force can be installed instead of one drive mechanism. In the case of one actuator, the second metal structure of the actuator is redundant and is not taken into account in the calculation. The positive side of using the two actuators is that they balance the steel structure of the drive assembly on both sides, thus evenly distributing loads from the motors to the structure [6].



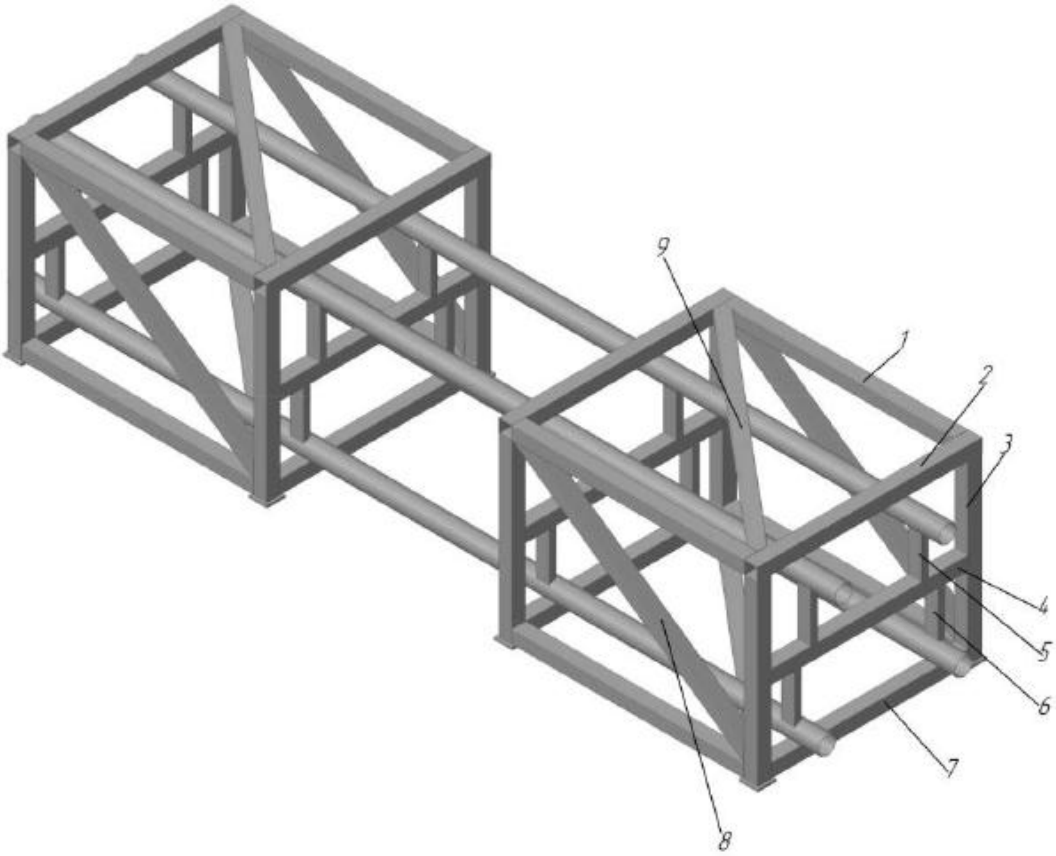
Steel structure of conveyor drive station with suspended belt: 1 - transverse rod; 2 – brace; 3 - vertical strut;
4, 5, 6 - longitudinal rod; 7 shows the longitudinal support of the drive mechanism;
8 - brace of drive mechanism support; 9 - transverse support of mechanism drive; 10 - longitudinal support of drive mechanism; 11 – vertical rack; 12 – раскос; 13 - vertical strut of cargo branch;
14 is a vertical stand of the idler branch; 15 - transverse rod;
16, 17 - brace

Figure 9- Structural diagram of the metal structure of the drive station.

Structural diagram of metal structure of linear section.

Several options are possible. Figure 10 shows a universal version of the steel structure. The main part of the power structure of the linear section consists of the following groups of rods:

- longitudinal (1);
- cross (2,4,7);
- vertical (3,5,6);
- braces(8.9).



Metal structures of line sections of conveyor with suspended belt:
1 is a longitudinal rod; 2 - transverse rod; 3 – vertical
core; 4 - transverse rod; 5 - vertical strut of cargo branch;
6 - vertical stand of idle branch; 7 is a transverse rod; 8 – brace;
9– brace

Figure 10 - Structural diagram of metal structure of linear section.

Solution of problems of conditional parametric optimization of main structural units of steel structure of conveyor with suspended belt and conditional optimization of metal structure as a whole is realized with the help of computing complex NX. The use of the complex allows not only to calculate strength characteristics of the metal structure by the method of finite elements, but also to determine optimal geometric characteristics of cross sections of rods and braces.

At initial stage initial version of metal structure is checked under condition of steady-state operation of conveyor with full loading of belt according to first limit state. The original version of the steel structure is a frame model (Figure 11), corresponding to the universal structural scheme of the optimized main conveyor assembly. The geometric dimensions of the skeleton model meet the design specifications for the suspended belt conveyor. A frame model is an assembly that includes structural elements such as drive and tension stations, a linear section, and guides. This model is built into the NX CAD subsystem [6].

The structure model is then converted into a finite element design diagram (Figure 12). Generation of finite element grid is performed in advanced simulation module of NX software complex. In this case, the subassemblies are divided into groups that later participate to varying degrees in the optimization process. Each member of the group is divided into a predetermined number of finite elements to calculate the metal structure by finite element method. The number of finite elements is taken from the calculation of 20 elements per 1 meter of the length of the structural element, which allows to obtain an accurate result of stress distribution with minimum time losses.

Groups of elements are assigned the necessary material, the physical and mechanical characteristics of which are included in the library of structural materials (Figure 13).

The type and dimensions of cross sections of structural elements are determined by selecting from the database categories of recommended profiles: rectangular and circular pipes, angle, channel (Figure 14). Conditions of attachment (rigid attachment) of steel structure of conveyor with suspended belt are specified. The loads acting on the steel structure are selected for the drive station - from the dead weight of the steel structure of the drive drum Rpb, the weight of the drive device Rp and the tension of the N1 belt; Tensioning station - due to dead weight of steel structure of tensioning drum Rnb and tensioning of belt N2; Linear section - from side of suspension from weight of conveyor belt with weight on guides of cargo run F1 and without weight - On idle F2 longitudinal forces on guides due to action of rolling friction on side of suspension, belt and weight on cargo run T1 and without weight - on idle T2. The dead weight of the steel structure is also taken into account. The universal structure diagram of the steel structure of the suspended belt conveyor is shown in Figure 11-14 [10].

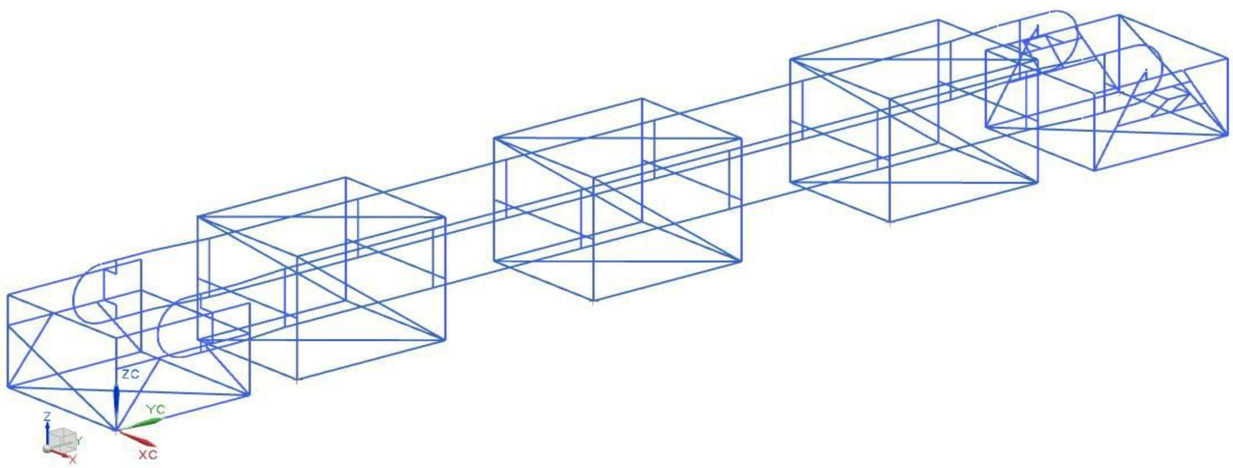


Figure 11- Conveyor Metal Structure Geometry Skeleton Model

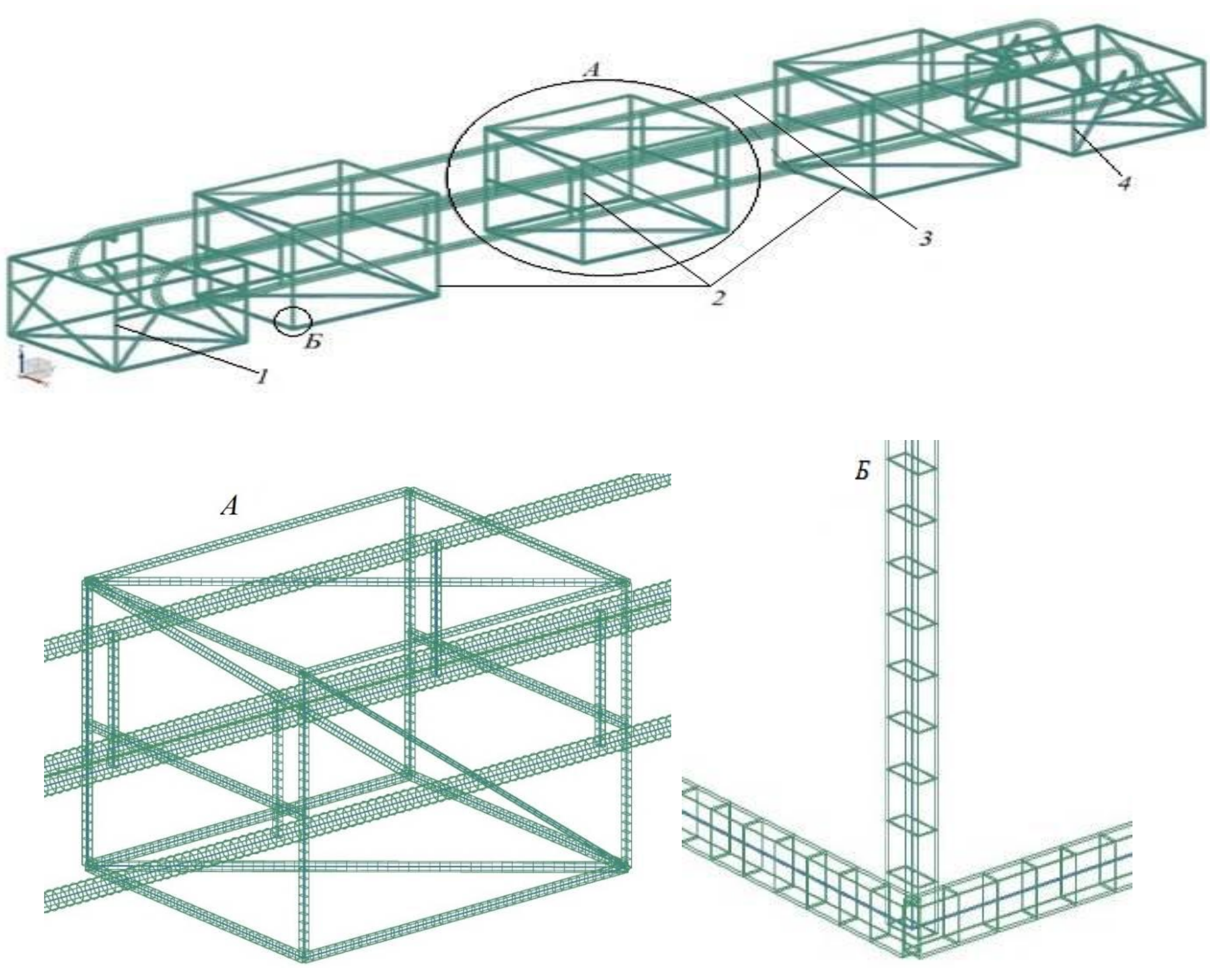


Figure 12 - Finite element diagram of steel structure of conveyor with suspended belt: 1 - tensioning station; 2 is a linear section; 3 – guide; 4 - drive stations

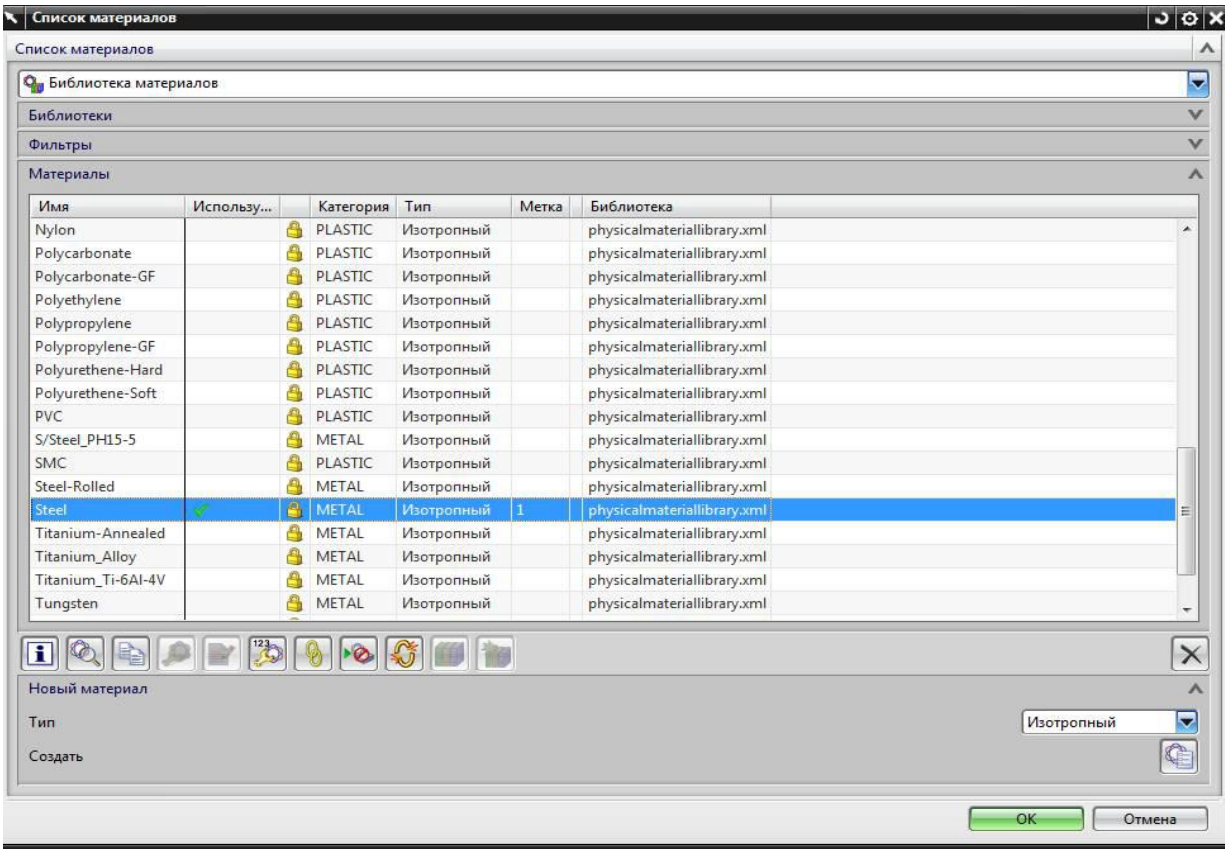
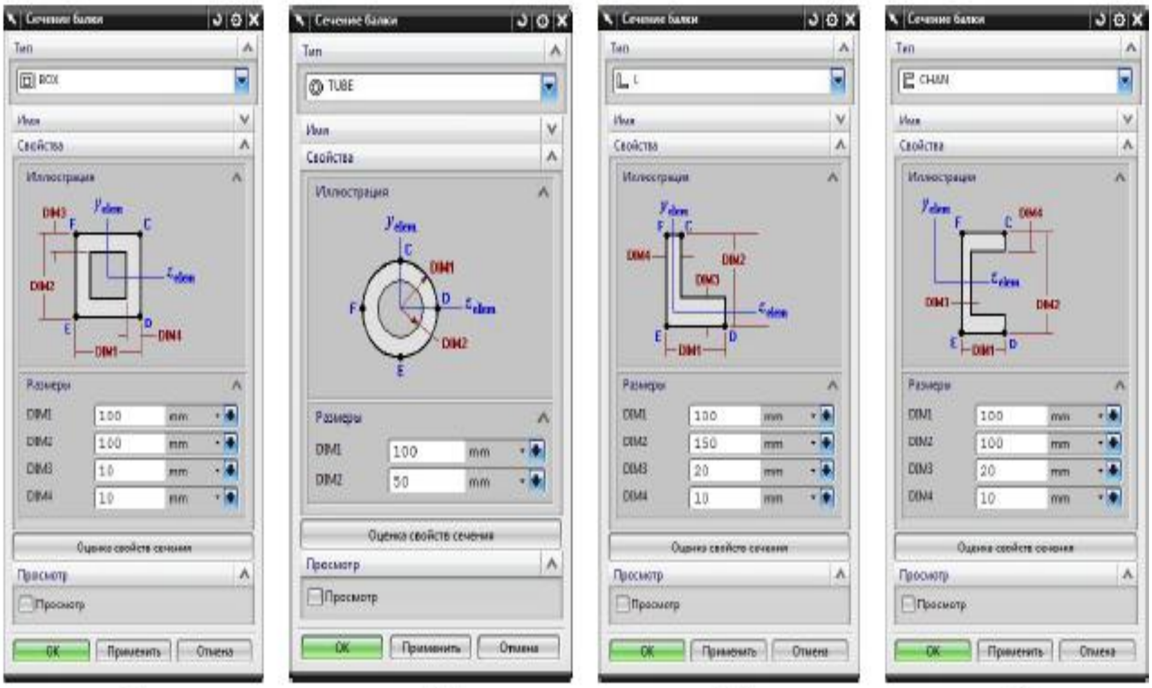


Figure 13 - Select Material from Library



а) б) в) г)

Figure 14- To select a cross section profile type and dimensions for a part: A-rectangular pipe; B-circular pipe;in- a corner; - a channel

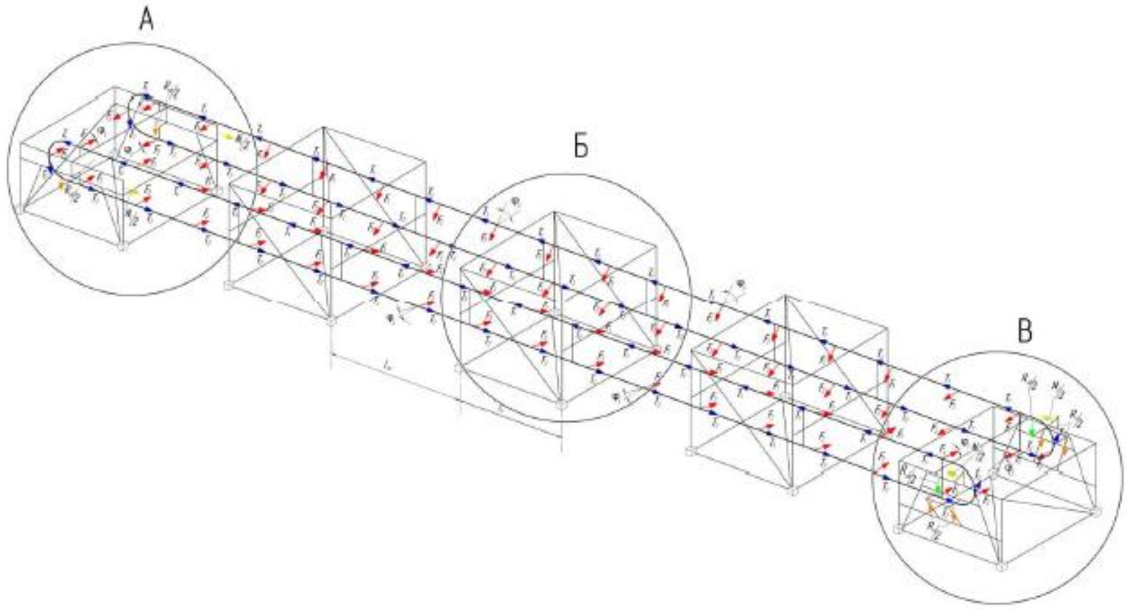


Figure 15- Universal design diagram of conveyor support structure with suspended belt for optimal design

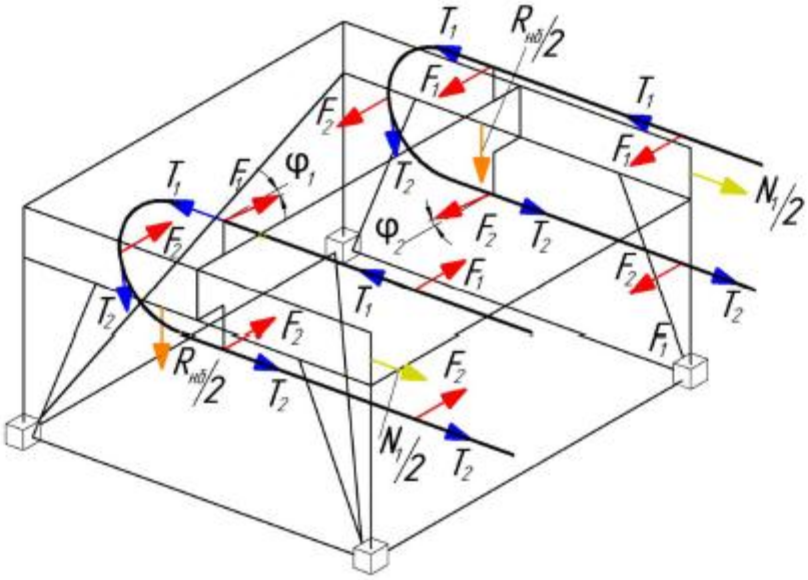


Figure 16-Universal design diagram of the load-bearing structure of the conveyor tensioning station with suspended belt for optimal design

Initial version of metal structure passes serviceability check on the first and second groups of limit states for conditions of stationary operation of conveyor with full loading of belt with transported load. Internal force coefficients (axial force N, transverse force Q, bending moment M), equivalent stresses and deviations in all structural elements of the optimized conveyor are calculated. Values of minimum loaded rods (not more than 5... 10% maximum load), which can be excluded from the structure under conditions of strength, and maximum loaded rods

(90... 100% maximum load) are shown in Figure 19-22. The rod deflection lever and the bracket of the steel structure of the conveyor are shown in Figure 23 [8].

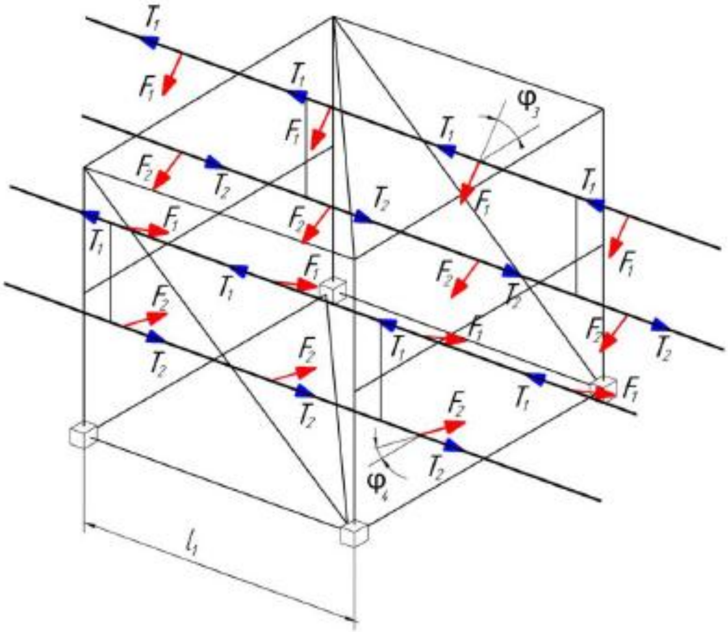


Figure 17-Universal design diagram of the support structure of the line section of the conveyor with suspended belt for optimal design

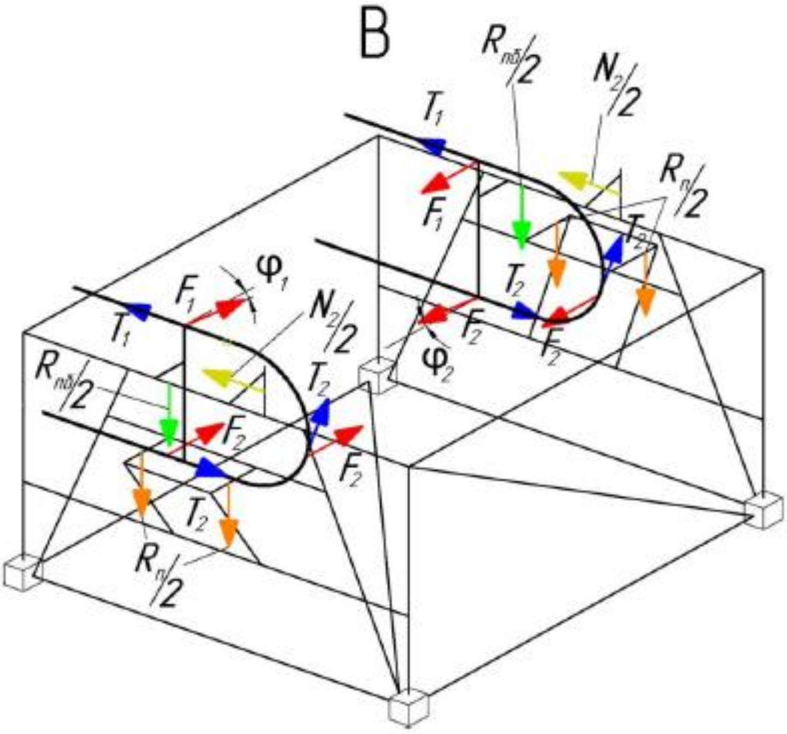


Figure 18- Universal design diagram of the load-bearing structure of the conveyor drive station with suspended belt for optimal design

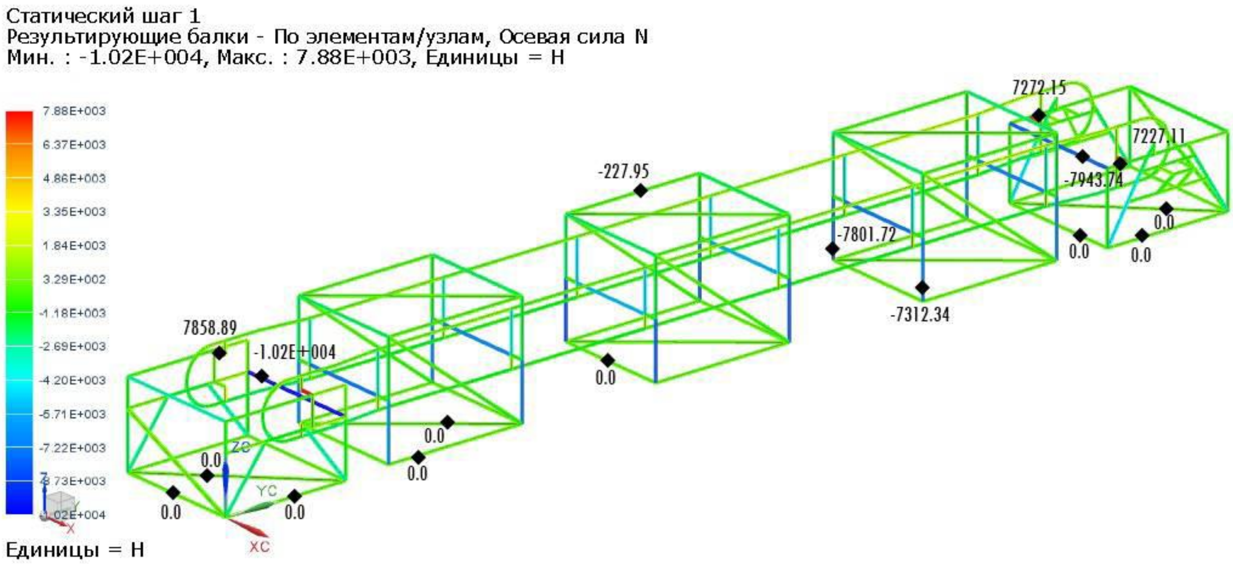


Figure 19- Axial forces N in conveyor steel structure rods and braces

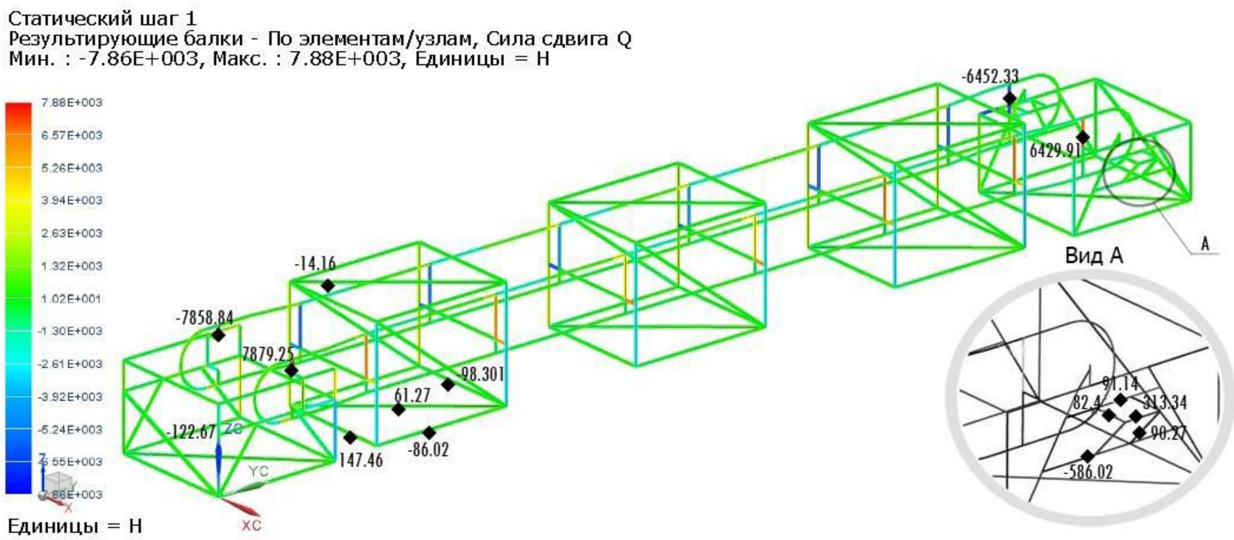


Figure 20-Transverse forces Q in conveyor steel structure rods and braces

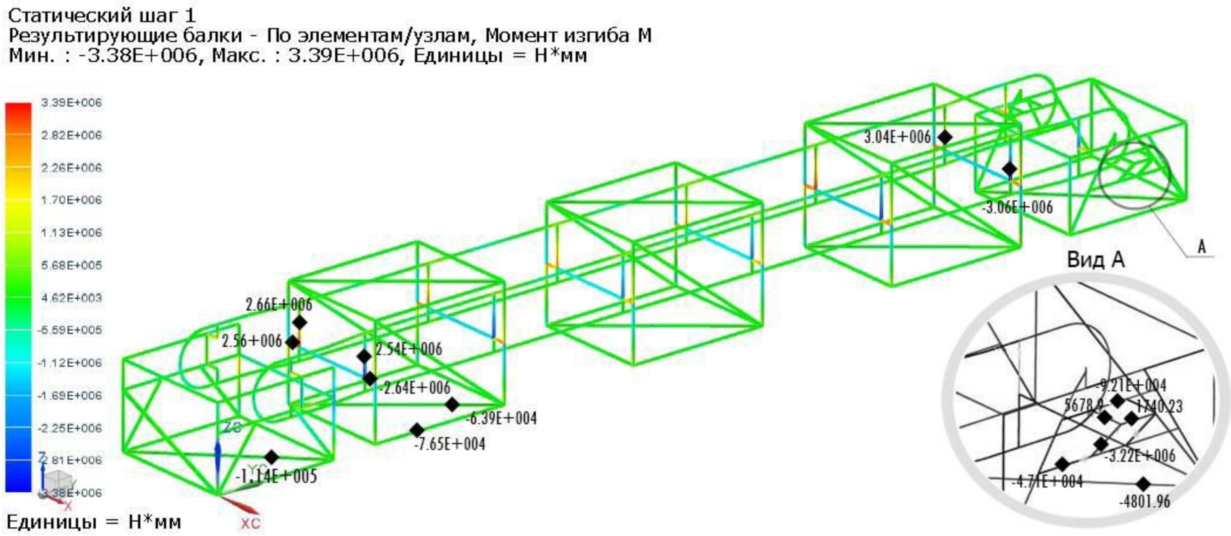


Figure 21- Bending moments M in the rods and braces of the steel structure of the conveyor

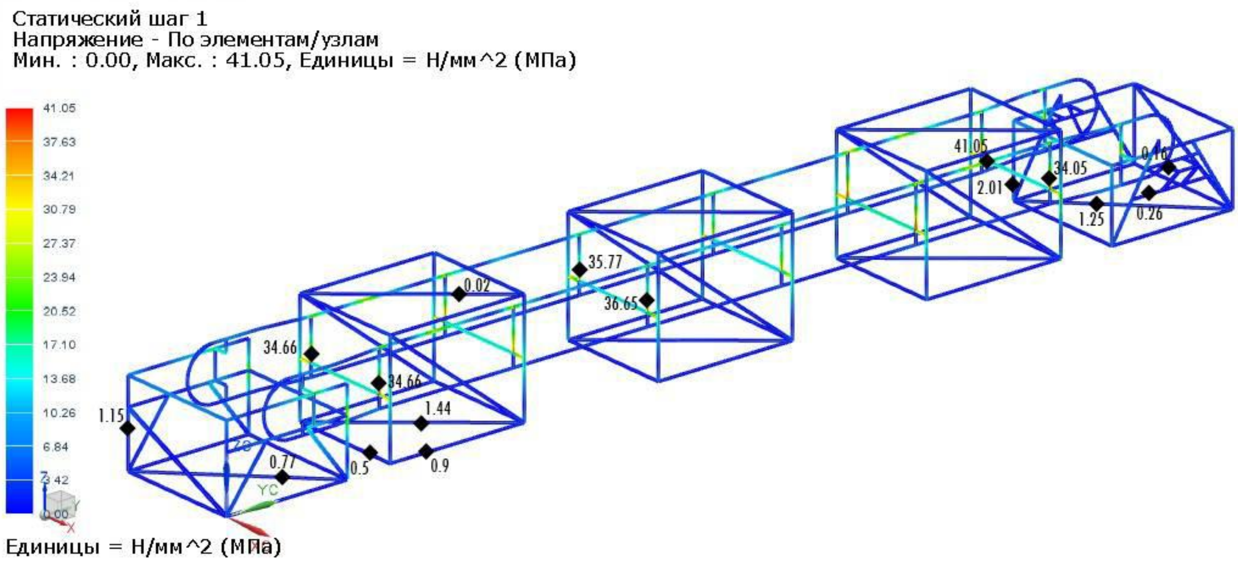


Figure 22 - Equivalent stresses in rods and braces conveyor metalwork

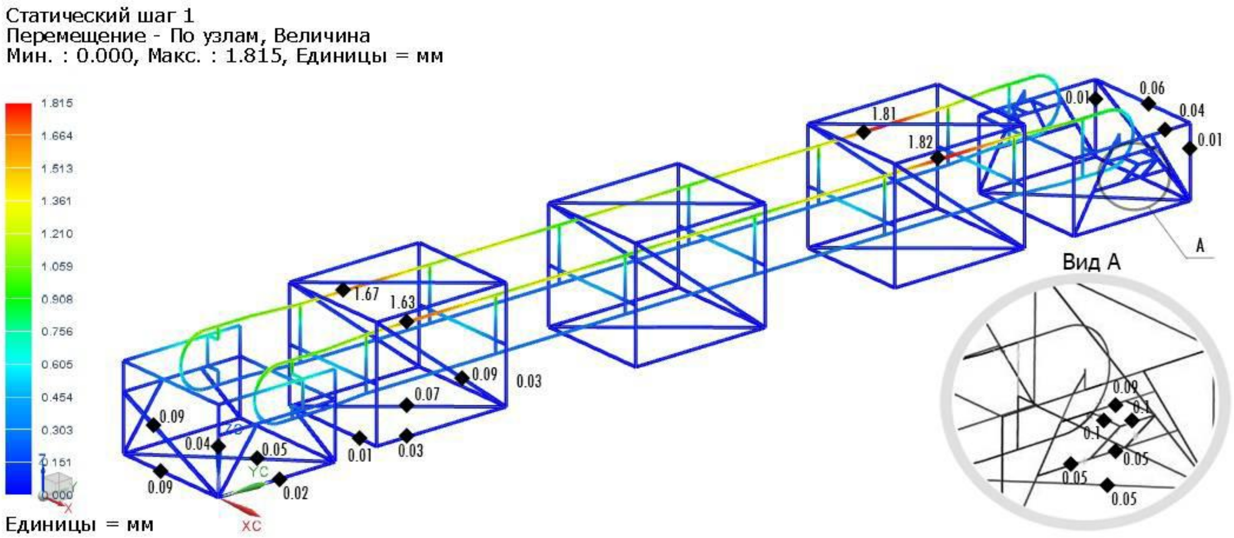


Figure 23 - Rod deflection boom and conveyor steel structure braces

Analysis of results of calculation of initial version of metal structure is based on obtained assessment of stress-strain state of structural elements forming metal structure. Components experiencing low equivalent stresses (not more than 5... 10% yield strength of the material, i.e. up to 10... 20 MPa) are excluded from the structural scheme of the steel structure. Where it is not possible or practically impossible to exclude them for structural reasons, the dimensions of their cross sections are reduced.

CONCLUSION

The materials displayed in this monograph reflect the comes about of advanced hypothetical considers of current issues of plan and computer modeling of transports with suspended carrier belt prepared with different sorts of drives - concentrated and distributed. Developed complex of numerical models of transport with suspended belt and disseminated drive, counting numerical show of discrete segment of suspensions and scientific show of transport as a entire, permits to appraise and select sound plan parameters of transport components at plan organize. Numerical examination of numerical show of discrete area of transport permitted to set up a number of vital physical regularities deciding conditions of energy-efficient working of dispersed drive and to realize their sound choice of fundamental plan parameters of drive and non-drive suspensions of load-carrying belt. In expansion, calculations of the pipeline demonstrate utilizing the CAD/CAE-based NX program have yielded comes about.

The results of the research, reflected in the monograph, make a certain contribution to solving the current scientific and practical task of increasing the efficiency of using continuous transport machines intended for transhipment and transport works in almost all sectors of the economy.

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