ABSTRACT

dissertation for the degree of Doctor of Philosophy (PhD) in the field of preparation 8D071 – «Engineering and practice of engineering», in the educational program 8D07101 – «Mechanical Engineering»

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The dissertation topic: «Research and development of a rotary conveyer design based on ensuring the interaction of articulated joints».

The relevance of the dissertation work. In Kazakhstan, coal reserves lying in ideal mining and geological conditions are running out. The use of rotary scraper conveyors solves this problem and involves off-balance sheet mineral reserves in the development. The rotation of the scraper conveyor by 90° introduces new kinematic connections, changes the dynamics of the system and the stress-strain state of the hinge systems for turning the conveyor belt from any angle, without which it is impossible to determine the wear zones, strength and reliability of parts.

There are no methods for calculating such tasks based on the multibody dynamics of motion in relation to conveyor rotary systems, and the presence of a turning zone from a group of solutions with the ability to do this starting from any one dramatically changes the nature of the stave loading in view of the rebuff of the scrapers, which significantly complicates the possibilities of their design and calculation. Simplifying the same technique when reducing tasks to the movement of a single body distorts the results obtained, leads to non-technological design: scraper breakdowns and wear of the contacting zones. Therefore, solving the problem based on simulation modeling of a multibody dynamic hinge system using discretization of dynamic equations and the finite element method combined with oscillography of work processes and measurements of its parameters during sequential assembly of the conveyor is an urgent area of research. At the same time, ensuring the manufacturability of structures consists in influencing its many parameters, which leads to technological rationality, inheritance and durability.

The hypothesis of the study is the assumption that it is possible to rotate the conveyor by 90 degrees due to the connection of the laths with hinges spaced on the sides and the steady movement of scrapers with rollers in contact with their sides while ensuring the manufacturability of the structure.

The purpose of the study: development, modeling and research of a new rotary hinge system of a scraper conveyor to ensure its optimal assembly, strength and the ability to work in robotic modes.

The object of research: a hinged system of lathes in interaction with a traction body and a method of simulation of a new design of a rotary scraper conveyor.

Subject of research: features of the formation of the load on the pivoting joints of the rotary conveyor to determine the zones of intense loading of parts, their wear and strength.

To **achieve the goal**, the following tasks have been solved:

- analysis of design schemes, technological conditions for ensuring the interaction of rotary hinge conveyor systems, assemblies that ensure the operability of the structure;

- development of a technique for simulating the movement of a scraper traction body and a stop in the conveyor rotation zone to analyze the stress-strain state, wear of contact zones and structural strength;

- creation of digital models of mechanical devices for use in databases during manufacture and operation;

- development of experimental research methods and their implementation for a new two-drive system of a full-size conveyor with hydraulic tension jacks with a stroke of up to 0,5 m and small stands;

- development of technology for assembling a complex conveyor structure using multidimensional classifications for databases.

Research methods:

- system analysis of rotary conveyor systems, in determining ways to improve the manufacturability of the mechanisms being developed, ways to improve their structure, assembly procedures with the identification of their features, management in databases with infological models of multidimensional classifications;

- methods of linearization of equations of dynamics and finite element technologies in Adams and Mechanical APDL (Ansys) packages, taking into account the accelerated movement of parts, when determining the stress-strain state, zones of the limiting state of the material and possible wear;

- methods of conducting experimental studies based on modern recording equipment: hydro sensors, frequency converter, oscilloscope, serial and developed bench equipment, load devices and elements simulating conveyor stretching with video recording of the studied dynamically changing procedures and wear control of contact zones.

The scientific novelty of the research is as follows:

Based on the first-developed methods of simulation modeling of the loading of a two-drive rotary conveyor with hydraulic tension, with accelerated movement of its elements and methods of movement of a traction body with scrapers along the sides of the gratings in the turning zone, rotated relative to each other at an angle of up to 15 degrees, the following are established:

- distributions, accelerations and support forces of the scrapers, which increase as they approach the junction of the gratings, reaching values up to 0,45 kN;

- dependences of the distribution of the support reactions in the hinges of the grid group in the 90° rotation zone and a pulling force of up to 40 kN was obtained;

It is established that the technological gap between the slats of 8-9 mm, simplifying the design, provides a reversible mode of operation of the conveyor and, being a random variable with a normal distribution law, causes the use of the method of incomplete interchangeability of the assembly, while in calculated terms the angular transverse and longitudinal displacements of the ends are taken into account and it is necessary to finalize the vertical ends of the sides at the final stage of their manufacture;

It is established that the stress-strain state of the sides during the movement of the scraper roller does not cause their further plastic deformation with a diameter of at least 40 mm, which ensures the small size of the structure, the reverse operation mode;

For the first time, constructive and kinematic schemes of the grid turning units have been developed when the scraper traction body is stretched by a hydraulic system with a stroke of rods up to 0,5 m with the ends of the scrapers equipped with rollers that meet the requirements of manufacturability, optimal assembly, long-term operation and patent novelty.

Scientific statements submitted for protection:

- safe operation of the conveyor at the entrance to the chamber is achieved with extreme rotations of neighboring grids not exceeding 20 degrees, and on average set at 15 degrees, the rotation and movement of the stave change the nature of the interaction of the scrapers with its sides, in the areas of hinged joints, and their identification is manifested in pressure oscillograms of hydraulic tension cylinders due to the occurrence of pulsation packets, characterizing the features of contact zones, load distribution and their wear;

- at the design stage of a new machine, the combined accounting of the manufacture, assembly, repair of its components, constructive adaptability to new application technologies and software innovations extends durability by 15-20 years, ensures manufacturability, reduces repair areas and facilitates the possibility of robotization of the main work processes;

- the creation of a rotation model of a multibody system with pivotally connected nodes in a volumetric environment was achieved through a complex computer simulation of this process, using a dynamic modeling package that selects equations of motion based on the elements introduced into the model and the construction of their connections, while for each model the following are performed: justification of the domain of existence, the effect of discontinuities of the mechanical system, decision control, experimental verification of the results on stands and a full-size sample of the conveyor in the process of sequential connection to the grid with an increase in their total turning angle to 90 degrees, the coincidence of simulated and real parameters with no exceeding of permissible deviations was obtained.

The author defends:

- the methodology for conducting simulation modeling of the movement of the conveyor stave with rotary and rotary-translational hinges, at accelerations adequate to the movement of the combine into the chamber, as well as the traction body with scrapers, in the area of the turn of the stave at 90° and pairs of lathes at an angle of no more than 15° with the determination of areas of intense wear when parts contact;

- the methodology for calculating the technological gap between the slats in the area of movement of the scraper roller, and the features of the assemblies: the assembly method for small-scale and serial production of the conveyor belt;

- multidimensional classification of the database to improve the efficiency of assembly analysis, kinematic relationships and analysis of the structure of data on the loading of parts;

- the results of experimental studies.

The practical significance of the work lies in:

- development and implementation of two modes of assembly of the rotary conveyor: for serial production of the rotary conveyor and for production in small batches.

In the first case, machine machining of the docking surfaces of the entire grid is performed to ensure a zero size of the technological gap in the linear state and 8-9 mm when turning the grids by 15 degrees with no more than a deviation from the right angle of the side sheet of 0,5 degrees across and along their section.

For the second case, with additional work on the gap surfaces in place and the addition of the method of incomplete interchangeability by grouping parts according to hole parameters:

- the methodology of constructive analysis using multidimensional classifications, data preparation and storage, assembly schemes, calculation of reliability and cost in the database;
- the methodology of bench and factory tests of small and full-size rotary conveyor in the turning zone with asynchronous and hydraulic drive with modern recording equipment with step-by-step connection to the assembly of new groups of racks and sections of the traction body;
- the results of the conducted research are also used in the educational process, for disciplines related to the design of technological machines and, in particular, for the bachelor's degree disciplines of the educational program 6B07111 «Design and construction of mining machines», «CAD GMO», as well as the master's degree programs 6B07111, 6B07104 «Special computer course», «Tools and systems for simulation of mining equipment». In addition, the results of the implementation of the scientific and practical results of the dissertation are planned to be used in future projects implemented in «KazTechPro» LLP. There is an act of implementation**.**

Compliance with the directions of scientific development or government programs

The dissertation was completed within the framework of the State Program for the Development of Mechanical Engineering in the Republic of Kazakhstan (2020-2025) and a grant from the Ministry of Education and Science of the Republic of Kazakhstan on the topic №AR05134441 «Development, manufacture and testing of a new design of a rotary assembly of a conveyor with a rotation of cargo flow at an angle of up to 90 degrees in the soil plane of the workings for downhole excavation and curved workings», according to priority: Energy and mechanical engineering, for the degree of Doctor of Philosophy PhD in the field of training 8D071 – «Engineering and practice of engineering», according to the educational program 8D07101 – «Mechanical Engineering».

Publications and work approbation

The results of scientific research obtained in the dissertation are registered in the act of introducing the results of scientific research into production activities at «KazTechPro» LLP and in the educational process for the bachelor's degree disciplines of the educational program 6B07111 «Design and construction of mining

machines», «CAD GMO», as well as the master's degree programs 6B07111, 6B07104 «Special computer course», «Tools and simulation systems for mining equipment». The author's certificate of completion of a scientific internship (Kemerevo, Russia) was also presented. During the writing of the dissertation, 1 Eurasian patent and 1 patent for inventions of Kazakhstan were obtained.

The main scientific provisions are reflected in 9 printed works. Of these, 2 articles are in journals included in the Scopus database, 3 articles in journals included in the list of publications submitted by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan, 2 abstracts of the international conference.

In the article «Investigation of a rotary system for excavating cameras» in the journal Coal, part of the Scopus database, DOI: http://dx.doi.org/10.18796/0041-5790-2023-6-55-60 the author has developed a database of multidimensional classifications with the ability to calculate reliability, assembly and cost of work with modeling the interaction of parts, investigated the issues of manufacturability of mining machines, including with constructive adaptability to new methods of application and extension their life cycle.

In the article «Modeling of a chamber excavation with a concave face shape» in the journal Coal, DOI: http://dx.doi.org/10.18796/0041-5790-2021-1-14-20 She considered the issues of conducting experimental studies in bench and factory tests of the rotary conveyor, as well as the scheme of its application.

In the article «Development of a hinged rotary conveyor system» in the journal «Bulletin of the L.N. Gumilev Eurasian National University, series of Technical Sciences and Technologies», the author proposed and investigated a system of rotary and translational hinges based on hydraulic jacks and established wear zones of their rods in the presence of an eccentric load.

In the article «Research of the peculiarities of conveyor rotation systems in the plane of transportation» of the journal Bulletin of the D. Serikbayev East Kazakhstan Technical University (Bulletin of the EKTU), the Scientific journal series of Technical Sciences and Technologies investigated the formation of a variety of loads on the hinge systems of the rotary conveyor, their distribution and maximum values, design features and new work schemes, developed assembly regulations on the slipway of the parts of the lathes of the rotary conveyor and the features of assembly in the linear and expanded state of the lathes. An important point of assembly is to ensure zero gaps between the laths in a linear position, and no more than 8-9 mm after turning by 15 degrees. For this, a slipway assembly of the conveyor is proposed, the stages of which are recorded in the database. Bench studies, constructive analysis based on the results obtained, taking into account the launches of a full-scale layout of a drive with a gear motor and hydraulic tensioning systems of a rotary conveyor, show the adequacy of the modeling methodology to real working conditions.

The structure and scope of the dissertation

This dissertation work consists of the following parts - introduction, 4 sections, conclusion, list of sources used and 3 appendices. The dissertation is presented on

165 pages of typewritten text, contains 83 figures, 2 tables and a list of references consisting of 92 titles.

The results of the study and the main conclusions. Scientific research in the dissertation has obtained new data and patterns that provide a solution to an important applied problem: the development of a design, technological conditions for ensuring the interaction of hinged joints of a rotary scraper conveyor, which will ensure the in-line transportation of solid minerals during their excavation by a short face to involve in the extraction of complex coal reserves, the volumes of which are not less than mined.

Based on the conducted research and their generalization, the following conclusions were obtained:

1. It has been established that the design of new equipment should take into account the possibilities of effective assembly, installation and disassembly schemes, the manufacture of components (their manufacturability), which is confirmed by the experience of their development in the Karaganda region. This prevents distortion of the structure of machine-building plants, their mechanical assembly shops and machine tools, which leads to an increase in the duration of operation up to 15-20 years.

2. The principles of manufacturability are met by the developed vertically closed conveyor design with a centrally located traction chain and a lateral arrangement of rotary and rotary-translational hinges, which ensured minimum dimensions in width of no more than 1 m, and the use of rollers on scrapers ensured the absence of growth of plastic deformation zones with a diameter of at least 40 mm, for the technological gap between the grids 8-9 mm. An essential element of increasing the life cycle of the system is to expand the scope of application for the extraction of hard-lying coal reserves.

3. When creating simulation models in MS Adams for the movement of sections of the chain with scrapers along the gratings and through their joints and the gratings themselves in the turning zone, in accordance with the Euler-Lagrange theory, new solutions require determining the area of their existence. As follows from the analysis of the equations of motion of the system, this is due to the fact that for a multibody system, the condition of holonomy of mechanisms when turning the shaft from the workings to the chamber for some nodes may be violated. In particular, it is necessary to take into account the transition of the scraper from one grid to another by changing its initial velocity in a new position. Multiple data of the hinge system, determining the change in the state of the conveyor, are located in a database, which, for the structural description of conveyor objects, is based on multidimensional classifications for automated systems.

4. A technology for assembling a limited batch (slipway assembly) has been developed to improve its accuracy by structurally modifying the gap in place and by grouping parts according to deviations from the average sizes of the assembly chain, for example, hole diameters d_1, d_2...d_i of the eyelets and the values of the convergence of the center of their axes to the surface of the conveyor side.

5. In serial production, assembly can be used with subsequent machine processing of the butt surfaces of the grid in their assembled state. The technological gap is determined by calculation in 3d, with an average value of 8-9 mm, is random with a normal distribution law, while using the method of incomplete interchangeability is recommended for mass production.

6. The safe movement of the scraper roller is achieved with a diameter of at least 40 mm, which ensures the small size of the structure, the reverse operation mode in the absence of growth zones of plastic deformation of the material.

7. Methods have been established for calculating the modes of movement of the traction chain with scrapers resting on the side of the conveyor in the turning zone and calculating reactions in the hinges of the shaft, while the maximum value occurs on the head rack, with a pulling force of 40 kN.

8. Industrial tests of articulated rotary conveyor systems were carried out and the steady movement of single-chain conveyor scrapers in the turning zone was justified, which confirmed the results of simulation modeling of the movement of scrapers along the sides of the rack and the conveyor stave in the wake of the combine when turning the stave at an angle of up to 90 degrees.

9. The results of theoretical calculations and simulation modeling in the Adams and Ansys program correspond to the production experiment.

10. The work was carried out within the framework of the State Program for the Development of Mechanical Engineering in the Republic of Kazakhstan (2020-2025) and during the preparation and implementation of the grant of the Ministry of Education and Science of the Republic of Kazakhstan «Development, manufacture and testing of a new design of a rotary assembly of the conveyor with a rotation of cargo flow at an angle of up to 90 degrees in the plane of the soil of the workings for downhole excavation and curved workings».

11. The developed simulation techniques and their programs, studies of the stress-strain state of parts and areas of intense wear, technical assembly regulations are taken into account in the Task for the development of a stand – scraper rotary conveyor in full-size design with an asynchronous motor and a hydraulic tensioner drive, which is the basis for creating a prototype industrial rotary conveyor for chamber excavation.