ABSTRACT
of the dissertation for the degree of Doctor of Philosophy (PhD)
in the field of training 8D071 – "Engineering and engineering",
according to the educational program 8D07102 – "Mechanical Engineering".

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DESIGN DEVELOPMENT AND DETERMINATION OF RATIONAL PARAMETERS OF A SCREW FEEDER OF A MILLING-ROTARY SNOWPLOW EQUIPPED WITH A BLADE ACCELERATOR

The relevance of the dissertation work. The dissertation was carried out within the framework of the State Program of infrastructural development of the Republic of Kazakhstan "Nurly Zhol" for 2020-2025, for the degree of Doctor of Philosophy PhD in the field of training 8D071 – "Engineering and Engineering", the educational program of the PhD PhD 8D07102 – "Mechanical Engineering".

The intensive development of the industry of the Republic of Kazakhstan leads to an increase in transportation not only in summer, but also in winter, during which snow anomalies occur, due to which traffic stops on roads and airfields are closed, which, in turn, determines increased requirements for work efficiency, for example, speed and cleaning ability large volumes of snow, to the power expended on it, etc., snowplows, especially milling and rotary ones, used when performing emergency snow removal operations at high-performance rates.

There are a large number of various equipment for dealing with snow drifts (with plow, milling, brush and other working bodies), the most versatile and effective of which are milling-rotary snowplows.

The disadvantages of the working process of known snowplows include: high traction resistance; significant energy consumption for movement; imperfection of the design, leading to the formation of a prism of dragging snow mass in front of the working body, the movement of which is forced to expend additional energy (power).

There are known designs of snowplows, the working bodies of which are equipped with accelerators of the working process, including blade-type accelerators. These accelerators, due to the autonomous high-speed processing of the snow mass accumulating in the center of the working body, contribute to its timely supply to the rotor-thrower, however, they have a number of design flaws that prevent the free passage of snow into the throwing zone. All known accelerator designs, due to the fixed and necessary fasteners to the body of the working body or due to the massive accelerator drive located in the center of the screw feeder, directly opposite the throwing rotor, slow down the incoming snow mass and themselves contribute to the formation of a dragged prism of snow, for the forced transportation of which a significant part of energy is spent.

Studies of the working bodies of snowplows, in which blade accelerators, together with a rational change in the angle of elevation of the feeder screw belt,

would exclude the formation of a snow-dragging prism in front of the working body and, thereby, would allow redistributing the released part of the energy previously spent on dragging the snow prism, for example, from the mover to the working body, and in turn the queue would provide an overall increase in the performance of the snowplow, there are none.

The lack of studies of the working process of blade accelerators, as well as studies of the influence of the angle of elevation and inclination of the screw feeder belt on the resistance forces and torque determine **the relevance of the study**.

The hypothesis of the study is the assumption about the possibility of effective cleaning of roads from snow debris by milling-rotary snowplows due to the use of blade accelerators and the installation of a rational angle of lifting of the screw feeder belt.

The aim of the study is to establish dependencies describing the working process of a screw feeder and a blade accelerator of a milling-rotary snowplow.

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

- a constructive analysis of patent and scientific and technical information was carried out, as well as trends in the formation of working equipment designs of milling and rotary snowplows (hereinafter referred to as FRS) were determined;
- designs of screw fed feeders equipped with a blade accelerator have been developed;
- a probabilistic assessment of the snow background of the operation of snowplows in the Republic of Kazakhstan has been determined;
- a mathematical model of the process of interaction of a milling screw feeder and a blade accelerator with the snow mass being developed has been developed and investigated;
- experimental models of a Fed screw feeder with a blade accelerator have been developed and the results obtained analytically have been confirmed;
- the design of the FRS screw feeder with a rational angle of lifting of the screw belt and an original method of mounting and independent drive of the blade accelerator is proposed, which ensures maximum efficiency of cleaning highways from snow blockages.

Research methods. The complex method of scientific research was the basis of the dissertation research. Theoretical research was based on the use of methods of the theory of numerical solutions to mathematical problems using computer technology and simulation of the interaction of a screw feeder with a blade accelerator of the Federal Reserve with a snow mass, as well as scientific provisions of theoretical mechanics and physical modeling in relation to a screw feeder and a blade accelerator of the Federal Reserve.

Experimental studies consisted in conducting a passive full-factor experiment using the developed experimental setup of the working body of the Federal Reserve and data analysis in Excel.

During the dissertation research, the following application software packages were used: AutoCAD, COMPASS-3D Viewer, MATLAB, Microsoft Visual Studio C#, STATISTICA, EXCEL, 3D Surface Plotter.

The scientific novelty of the study is as follows:

- experimentally confirmed the hypothesis about the possibility of effective cleaning of roads from snow debris by milling-rotary snowplows due to the use of blade accelerators and the installation of a rational angle of lifting of the screw feeder belt;

- theoretically, the dependences between the components of the resistance forces to the interaction of the screw feeder with the material being developed on the angle of elevation of the helical line and the rotation frequency of the semi-cutter feeder, the working speed of the snowplow are established;

- theoretically, the dependence of the torque on the angle of elevation of the helical line, the operating speed of the FRS and the rotational speed of the screw feeder is established;

- the dependences of power costs on the speed of movement and the angle of elevation of the helical line of the feeder are obtained experimentally;

- theoretically, the kinematics of the movement of snow mass along the blades of the accelerator of the screw feeder of the FRS during their unloading has been established;

- theoretically, the resistances on the accelerator blades and the limiting angular velocities of the blade accelerator are established.

Scientific provisions submitted for protection:

- the use of blade accelerators in the working bodies of the Federal Reserve makes it possible to reduce the resistance on the working body and prevent the formation of a snow drawing prism in front of it;

- regularities of changes in the forces of resistance to the interaction of the screw feeder with the material being developed from the angle of elevation of the helical line and the rotation frequency of the semi-cutter feeder, from the operating speed of the snowplow;

- regularities of the influence of the diameter, geometric shape and rotational speed of the blade accelerator on the resistance forces, the moment and the total power of the FRS workflow;

- the rational angle of elevation of the screw line of the FED feeder is the angle $\alpha = 18\text{-}20^0$;

- the total power spent on the working process of a screw feeder with a blade accelerator is reduced by an average of 12% compared to the power costs on the working body of a snowplow of a traditional design.

The author defends:

1. Design solutions of a new milling-rotary snowplow, the screw feeder of which is equipped with a blade-type accelerator;

2. A mathematical model that allows you to calculate the change in the vertical Pv and horizontal Pg components of the resistance forces and torque Mkr on the screw feeder, depending on its parameters and operating modes of the snowplow;

3. Results of experimental studies;

4. The methodology for calculating the screw feeder of the Fed.

The object of the study is the workflow of the Fed screw feeder equipped with a blade accelerator.

The subject of the study is the regularities of the working process of interaction of the Fed screw feeder equipped with a blade accelerator with a snow massif.

The practical significance of the research is:

- in the developed designs and methods for calculating the parameters of the FRS with a blade accelerator, which allow to increase the efficiency of the process of operational snow removal of operated roads in extreme conditions;

- in the developed experimental stand for the study of the physical model of the Federal Reserve System, which allowed us to determine the experimental dependences of the components of the resistance forces, torque and snow throwing range on the parameters of the screw feeder, and the blade accelerator, and their operating modes.

The results of the research are properly designed and **implemented** in the workflow of "Oskemen-Tazalyk" LLP.

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Summary. In the first chapter of the dissertation, a review and analysis of well-known designs and theoretical studies in the field of snowplows are carried out. The analysis of patent and technical solutions of the Federal Reserve is carried out. The goals and objectives of the study are set.

In the second chapter, a probabilistic assessment of the snow situation of the operation of snowplows on the territory of the Republic of Kazakhstan is given. An estimate of the possible snow density and snow cover temperature is given. A probabilistic analysis of the basic physical and mechanical properties of snow has been carried out, polygons for the distribution of air temperature and volume mass of snow cover across the regions of the Republic of Kazakhstan have been constructed.

The third chapter is devoted to the theoretical analysis of the operation of the screw feeder of the milling-rotary snowplow. The forces and moments of resistance at contact of the screw feeder of the FRS with the developed snow are determined. The components of vertical and horizontal forces on the screw feeder of the Fed are found. The working process of the blade accelerator of the screw feeder of the FRS is investigated. The limiting angular velocities of the blade accelerator are calculated. The power and energy intensity of the screw feeder operation process were evaluated. The resistances on the accelerator blades have been determined, which have a significant impact on its energy consumption and efficiency. A mathematical model of the FRS workflow has been developed that characterizes the change in vertical and horizontal resistance forces and torque on a screw feeder depending on its parameters and operating modes of the snowplow.

The fourth chapter describes the methodology and equipment of experimental studies of the Fed model. The objective of the experimental studies was a qualitative and quantitative assessment of the influence of various modes of operation of the

Fed screw feeder on the power and energy parameters characterizing the working process of interaction of the Fed screw feeder with the developed environment and comparison with the results of theoretical studies. A factorial experiment was performed and numerical values of regression coefficients and their significance were determined, as well as the adequacy of models in processing experimental data of a multifactorial experiment was established.

The main functional models were obtained, presented in the form of regression equations for variables in kind, characterizing changes in torque, vertical and horizontal drag forces, as well as the range of snow mass throwing, which confirmed the hypothesis that it is possible to effectively clean roads from snow debris by the Federal Reserve through the use of blade accelerators and the installation of a rational angle of elevation of the screw feeder belt.

The fifth chapter is devoted to the analysis of the results of experimental studies of the efficiency of the Fed screw feeder. The analysis of the results of experimental determination of the angle of elevation of the helical line and the modes of operation of the screw feeder of the FED is carried out. The dependences of the horizontal and vertical components of the resistance to milling of the snow mass on the angle of elevation of the helix and the working speed of the FRS at a constant rotation speed and height of the developed snow are obtained. The throwing capacity of a screw feeder with an increase in the lifting angle of the helix and the nature of material transportation along its inner surface are analyzed. The dependences of power costs on the ratio of the relative and operating speeds of the FRS, the angle of elevation of the helix and the operating modes of the feeder are constructed. The efficiency of the process of throwing snow by the screw feeder of the FRS into the zone of operation of the rotor-thrower is analyzed. Detailed photograms of the workflow have been compiled with the fixation of the real picture of the operation of the screw feeder and the blade accelerator. The areas of rational parameters of the design and operating parameters of the screw feeder of the FRS are established.

Personal contribution of the dissertation. The work was done by the author personally, the author performed a patent analysis of known designs, a review of theoretical research in the field of snowplows. He developed and researched a mathematical model for calculating the parameters of the new FED equipped with a blade-type accelerator. He designed and manufactured experimental stands, modeled a special mixture simulating snow, and selected recording equipment. I obtained and compared analytical and experimental dependences describing the operation of a Fed screw feeder with a blade accelerator.

Publication and approbation of the work. The main provisions of the dissertation have been published in 18 scientific papers, including 3 articles included in the Scopus database with a percentile above 35 and one patent for an invention of the Republic of Kazakhstan cited in the Web of Science database, in 7 articles recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and higher education of the Republic of Kazakhstan, in 3 Eurasian patents and 2 patents for inventions of the Republic of Kazakhstan, in 3 articles included in the RSCI abstract base. All publications present

materials and results of theoretical and experimental studies of the working process of a screw feeder FED with a blade accelerator, giving an idea of the processes occurring both inside the snow mass and in the zone of its contact with a screw feeder or a blade accelerator FED, allowing you to choose rational parameters of the working process of snow removal and design parameters of snowplows. Additionally, the materials of the dissertation are presented in 6 theses of international scientific-practical and scientific-methodical conferences. The research results were reported and discussed at international scientific conferences: at the 79th (2021) and 80th (2022) MNMiNIK MADI (MADI, Moscow, Russia); at the VI and VII International Scientific and Technical Conference of students, undergraduates and young scientists "Creativity of young innovative development of Kazakhstan", VKTU, (2021, 2022, 2023); MNPC dedicated to the 30th anniversary of Independence of the Republic of Kazakhstan: "Modern Kazakhstan: Reforms of Education and Science" (2021), Eurasian Technological University; MNPC "Integration of science, education and production – the basis for the implementation of the National Plan" (Saginovsky Readings No. 13), dedicated to the 30th anniversary of Independence of the Republic of Kazakhstan (2021), Map.

The structure and scope of the dissertation. The dissertation work is presented on 174 pages of typewritten text, consists of designations and abbreviations, an introduction, 5 sections and a conclusion, includes 92 figures, 18 tables, a list of used sources from 123 titles and 6 appendices.

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The results of the study and the main conclusions. The dissertation contains new scientifically-based results, the use of which provides a solution to an important applied problem of developing a methodology for calculating the design parameters of the FRS with a blade accelerator, providing efficient high-speed cleaning of highways from snow debris with the least energy consumption.:

1. A constructive analysis of patent and scientific and technical information showed the advantages and prospects of the study of milling-rotor working bodies over other types of feeder designs compared, and also allowed us to develop a classification scheme of methods for improving the efficiency of FED feeders, carried out due to the rational organization of the snow removal workflow, excluding an increase in the engine power of the base machine.

2. 3 Eurasian and 2 Kazakhstani patents have been developed and protected for inventions of the design of screw feeders of the Federal Reserve System, which, due to the blade accelerator, increase the efficiency of the process of operational snow removal of operated roads with the lowest energy consumption.

3. A probabilistic assessment of the snow background of the operation of snowplows in the Republic of Kazakhstan has been determined, the volume mass of the snow cover and the temperature of which obey the law of normal distribution

with a probability of Rd = 95%. The most probable values of the cutting resistivity are 4.7-7.9, the coefficients of external and internal friction of snow are 0.07- 0.08, 042-0,45, respectively;

4. A mathematical model of the working process of the FED screw feeder has been developed, characterizing the change in the vertical Pv and horizontal Pg parts of the force and torque Mkr on the screw feeder, depending on its parameters (the angle $\propto$ of the helix lift) and the operating modes of the snowplow (the circumferential speed of the feeder ω and the working height of the snow H_0);

5. Experimental stands have been developed to study the physical model of the FED screw feeder with a blade accelerator, allowing to invert the process of interaction of the screw feeder with the material, as a result of which external interference from the movement of the FED screw feeder model is eliminated.

6. Analytically, the results obtained have been confirmed experimentally. When installing a blade accelerator on a screw feeder of the FRS with an angle $\alpha = 18^0$, the horizontal and vertical efforts of developing a snow mass and the moment of resistance on the working body are maximally reduced by 25-30%, compared with the traditional design of a screw feeder, and with an increase in the thickness of the developed snow layer, the efficiency of using a blade accelerator increases, which is realized in an increase in productivity by 28 - 30%.

7. An analysis of the efficiency of the Fed with a propeller feeder blade accelerator shows that the energy intensity of the interaction of the working body with the snow mass is 22-25% less compared to the existing traditional design, with a slight (1.5-2%) increase in metal consumption. The value of the integral indicator of the efficiency of the Fed decreases when installing a blade accelerator on a screw feeder by 25-30%.

8. Theoretical and experimental data have a discrepancy in the range of 11-18%, which indicates the reliability of the theoretical model and allows it to be used in engineering calculations;

9. The design of the FRS screw feeder with a rational angle of lifting of the screw belt $\alpha = 18^0$ and an original method of mounting and independent drive of the blade accelerator is proposed, which ensures maximum efficiency of cleaning highways from snow blockages. The experimental design has been tested and tested in real production conditions.