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Experimental Studies of the Equipment Operation Efficiency to Clean Snow and Ice Formations from Roads and Sideways

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Abstract. *The purpose of the work is to determine parameters of the working body and its operation modes, in which the most effective removal of snow and ice formations from the road surfaces is achieved, with the obligatory observance of the integrity and safety of the pavement and sidewalk surfaces. The article represents the developed design of the mounted shock-rotary working equipment for the destruction of snow-ice formations. Methods for calculating the design parameters of special working bodies of shear and impact action have been developed. The developed model of ice breaking allows increasing the efficiency of the icebreaking machine at the design stage in order to increase its efficiency by regulating and selecting its rational mechanical and geometric characteristics according to the given values of the cam penetration depth, strength, and ice thickness. An analysis of the experimental studies confirmed the adequacy of the model of cleaning the road surface. The relevance of the research and the expected social effect is justified by the possibility of reducing the number of accidents and winter injuries on the roads of the Republic of Kazakhstan.*

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Keywords: *snow, ice, snow-ice formations, impact icebreaker, working body, efficiency, road, sidewalk, model, safety.*

Introduction

An urgent problem for public utilities and road maintenance services within the winter months is that the cleaning and ice removal occurring on the bearing surface of highways, and sidewalks, significantly complicates the movement of pedestrians and driving a car, and sometimes makes them impossible [1].

Snow-ice formations (SIF) accumulating on highways and pedestrian sidewalks, consistent with their physical properties and external behavior, are often divided into unconsolidated, incoherent snow (loose), compressed, rolled snow, and transparent glassy ice [2]. With loose snow, the coefficient of adhesion of tires with a snow-covered surface decreases to 0.2, with rolled snow, the coefficient of adhesion of tires to the surface is 0.01...0.25, with the formation of glassy ice, the coefficient of adhesion of tires becomes 0.08...0.15. For comparison, the adhesion coefficient of dry asphalt is 0.7...0.8 [3].

To prevent slipperiness on roads and sidewalks in winter, a mechanical method is often used to remove ice from their surface [1-3]. An effective method of mechanical destruction of ice is impact. The authors in the course of the work on the project AP09258973 «New technology for the production of innovative ice-cleaning road equipment» under the grant of the Committee of Science of the Ministry of Education and Science of the Republic of Kazakhstan are developing working bodies of shock-destructive action with rectangular strikers for breaking ice on roads and sidewalks.

Experimental studies

Experimental work included carrying out experimental studies of the working body efficiency of the percussion action of the pilot-industrial model of the ice breaker.

The aim of the research is to determine the parameters of the working body and operation modes, in which the most effective removal of snow and ice formations from the road surfaces is achieved, with the obligatory observance of the integrity and safety of the pavement and sidewalk surfaces, as well as experimental verification and refinement of mathematical models for the formation of loads on working body of the ice-removing machine and interaction with ice and compacted snow of the strikers of the percussion action working body.

Experimental studies are carried out in accordance with the program and methods that establish the procedure for conducting tests to determine the parameters of the working body interaction of the ice-removing machine with ice and snow formations, determine the method for measuring the deformations of ice and the working body, stresses, and displacements.

After the manufacture of a pilot industrial sample (Figure 1), devices for loading and testing, and installation of measuring equipment, the experiment has been performed. It comes down to various loadings, measurements, and instrument readings.

Analysis of the results gives an idea of the stress-strain state of the investigated rotary working body and the SIF.

Experimental studies determined the required value of the ice destruction force (Figure 2) generated by the working body of the percussion action for the various production technologies for the ice removal since it seems problematic to measure the magnitude of the load on a single element of the working body.

At the same time, the properties of ice and its thickness have been determined.

During the interaction of the working body with ice, the horizontal and vertical stress response on the working body, as well as the magnitude of the deformation of the ice cover, are measured. The elements of the working body in various cases are loaded using a screw mechanism. The vertical force is imitated by hanging loads of a certain mass on the working body. The loading of the working body with a torque, if necessary, could be carried out using a hand hoist (through a cable stretched along the upper edges of the strikers and moored behind one of them). The load values are measured using an exemplary compression dynamometer and pressure gauge.

The thickness of the ice is determined using a caliper. Before testing, the total thickness of the ice cover is measured. The tests are carried out in various meteorological conditions on the surfaces of icy roads and sidewalks of the city. The developed ice cover is of natural origin with different structures. A comparative assessment of the actual and calculated

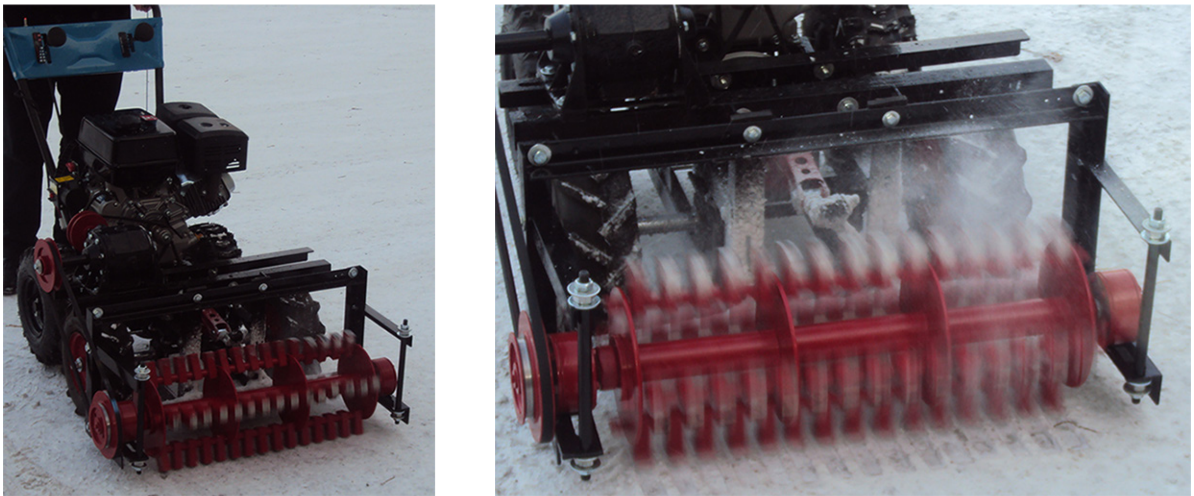

Figure 1 – General view of the small-sized self-propelled unit (SPU) with the percussion working body for the destruction of the SIF

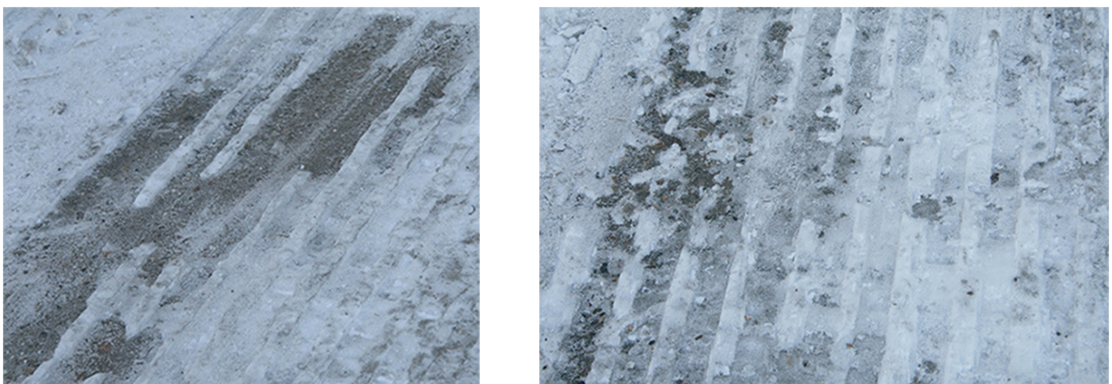

Figure 2 – The surface of the road section with the SIF after the passage of the SPU local control system

values of the impact forces acting in laboratory studies on the elements of the working bodies of the ice-breaking machine and on the developed ice base is carried out based on the processing the data of the signal taken from the strain gauges installed on the working body.

The test program included the following types of work:

a) Preparation of equipment for testing.

b) Carrying out preparatory work at the test site.

c) Carrying out the registration of the operating parameters of the processes under study.

To determine the parameters of the interaction of snow-ice formations on roads and urban areas with the working body of the impact action of the ice-breaking machine, earlier the authors obtained calculated dependencies to determine such parameters as the size of the working bodies and the modes of technology for cleaning ice formations.

When constructing a mathematical model of the interaction of snow-ice formations with the impactor, the following assumptions were made:

- the surface of snow-ice formations is a flat horizontal surface;

- physical and mechanical properties of snow-ice formations are constant throughout the entire lane of the ice-breaking machine, the temperature of the ice formation is assumed to be equal to the ambient temperature, the change in temperature along the ice thickness is considered absent due to the relatively small ice thickness;

- properties of ice, such as strength, hardness, and others associated with temperature changes, are also considered constant;

- the movement of the ice-breaking machine is rectilinear, and the rotation of the working body is uniform.

The rotating striker initially crashes into the developed environment with some force F. The expression for the force is obtained in the form:

$$F=\sqrt{(\frac{m_b\cdot v_c^2}{R})^2\pm(m_b\cdot g)^2\pm 2\cdot\frac{m_b\cdot v_c^2}{R}\cdot m_b\cdot g\cdot\cos\varphi}, \text{ N}, \quad (1)$$

where m_b – striker weight, kg; v_c – peripheral speed of the striker, m/s; R –radius of the rotor from the rotation axis to the hammer (strike) gravity center, m; $g=9{,}8$ m/s^2 – acceleration of gravity; φ – the angle between the striker gravity G_b and centrifugal force G_b.

The ice that forms on the road surface is not uniform in composition and structure. In addition, the shape of the striker itself will also affect the force of impact. The expression for determining the impact force of the striker will look like:

$$P_{ud}=K_1\cdot K_2\cdot P_{12c}\sqrt{2\cdot\pi\cdot L_{бB\min}}_{\max}, \text{ N}, \quad (2)$$

where $K_1=\frac{P_{\max}}{P_e}$ – correction factor that takes into account the physical and mechanical properties of ice upon impact (where P_e – reference impact force); $K_2=1+\frac{b_1}{2\cdot h}$ – coefficient taking into account the type of striker edge impact (where b_1 – impact edge length, m; h – ice thickness (SIF), m); $L_{\min}$ – minimum distance from the impact edge of the striker to its center of gravity, m; σ_B – compressive strength of the developed medium, MPa.

The total force of the ice cutting by the working body striker of the shock-rotational action can be determined from the following expression:

$$P_{rez}=\frac{C_0}{tg\beta}\cdot P_e\cdot h_1^{0.47}\cdot\frac{b_1}{K_{per}}\cdot(1+k\cdot t)\times \times(1+\xi\cdot v_c)\cdot\left(1+4\cdot h_1\cdot\sqrt{\frac{C_0\cdot\pi}{(1+2\cdot\mu)\cdot tg\alpha}}\right), \quad (3)$$

where P_e – reference impact force, N; k – coefficient that takes into account the change in the strength properties of ice depending on temperature; $k=0.04$ N/deg; ξ – coefficient taking into account the change in the strength properties of ice at different speeds v_c load application, N/(m/s); β – ice-breaking angle, deg; μ – Poisson ratio; for ice $\mu=0.36$; b_1 – the cutting edge width of the striker; h_1 – the height of the cut layer, m; t – the ambient temperature, deg.

Development speed value v_p (m/s):

$$v_c=\sqrt{v_p^2\pm(w\cdot R)^2\pm 2\cdot v_p\cdot w\cdot R\cdot\cos\varphi}, \text{ m/s}. \quad (4)$$

The mass of the striker can be determined from the following ratio:

$$m_b=\frac{2\cdot\pi\cdot h_l^3\cdot\rho_l}{3\cdot(\frac{v_c}{v_p}+1)}, \text{ kg}. \quad (5)$$

The total power of the machine for the destruction of the snow-ice formations can be determined as the sum of the powers for the destruction of the SIF itself and for the creation of tractive effort or as the sum product of the torque and the angular velocity of working body rotation of the impact action and the product of the machine speed by the value traction force.

$$N_{razr}=M_{kr}\cdot w+v_p\cdot P_m, \text{ W}, \quad (6)$$

where M_{kr} – torque, ω – angular speed of hammer (striker) rotation, s^{-1}, v_p – speed of car movement (m/s), P_m – tractive effort.

The experiments are carried out on a full-scale pilot-industrial sample of the working body. Experimental studies consisted of three stages:

1) study of the characteristics of ice as a developed medium;

2) verification of the ice development model with a single striker;

3) verification of the mathematical model of the entire working body as a whole.

The analysis of the received information and the conducted experiments revealed five factors that form the force of resistance to the development of ice. To determine the numerical values of the interaction parameters of the percussion working body with ice, the methods and techniques of the experiment planning theory are partially used. The magnitude of the ice development force created on the working body is taken as a response. The results of the research are summarized independences (graphs) and shown in Figures 3-6.

Figures 3-5 show graphs of the theoretical and experimental dependences of the ice chipping process, which have an acceptable, within the normal range, deviation from each other.

Checking the reliability of the experimental data by the Cochran criterion and the adequacy of the mathematical model by the Fisher criterion showed the reliability of the results for both criteria. The standard deviation ranged from 12 to 28%, depending on the studied parameters (Figure 6).

An important parameter describing the process of removing ice from road surfaces is the energy consumption during this process. Working torque and feed change from minimum to maximum values with a full rotation of the working body. An approximate definition of impact power shows (Figure 7) that when ice is removed from the territory by a special impact working body, 6% of the machine power is spent on removal, and 94% of its power is spent on crushing ice, that is, the power to move the machine with the working element also depends on ice crushing parameters.

Conclusions

An analysis of the data from experimental studies confirmed the adequacy of the model of cleaning the road surface proposed above, in which the strikers break the ice surface of roads with a blow, but bounce off the asphalt concrete surface, leaving its top layer intact.

Based on the mechanical and mathematical models, methods have been developed for calculating the design parameters of special working bodies of shearing and impact action, designed to remove ice

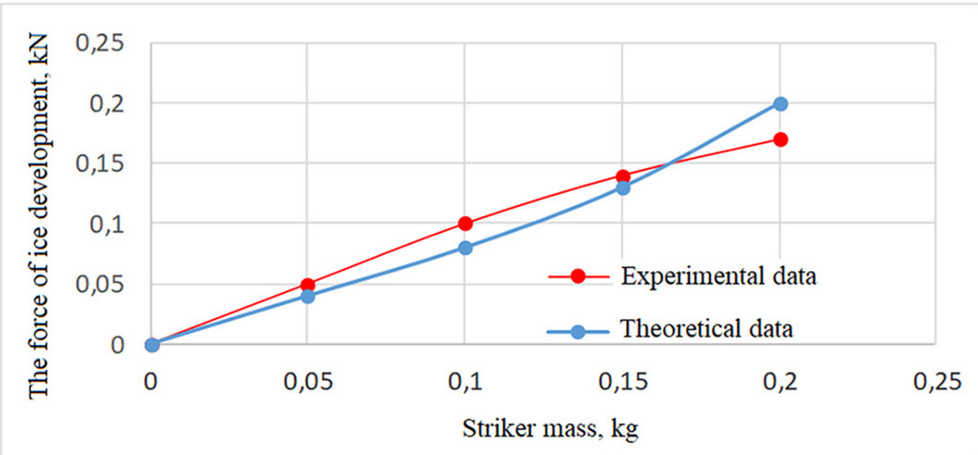

Figure 3 – Change in the force of ice development depending on the mass of the striker

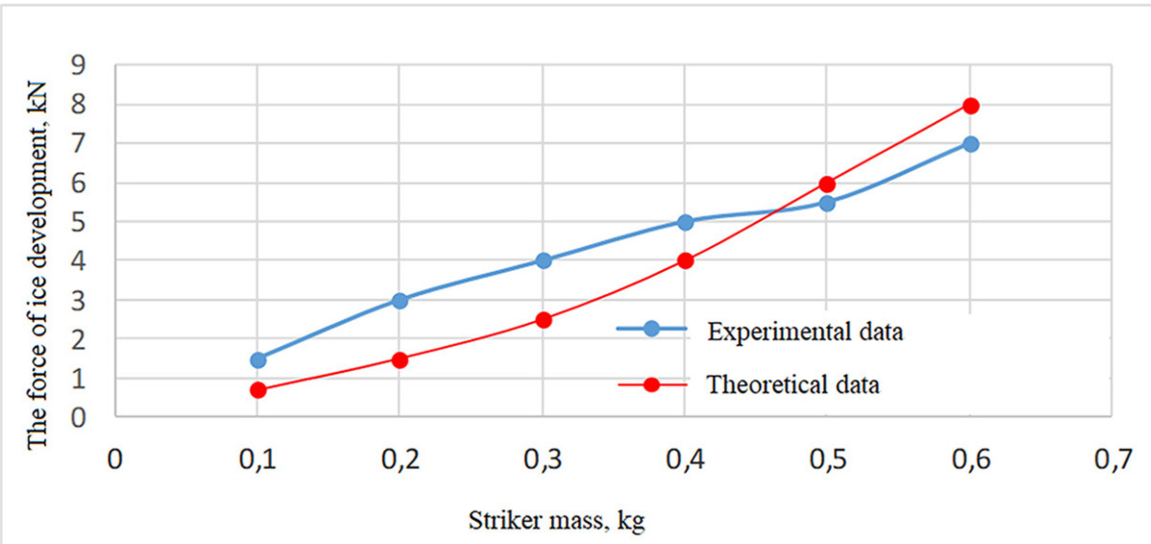

Figure 4 – Change in the force of ice development depending on the development speed

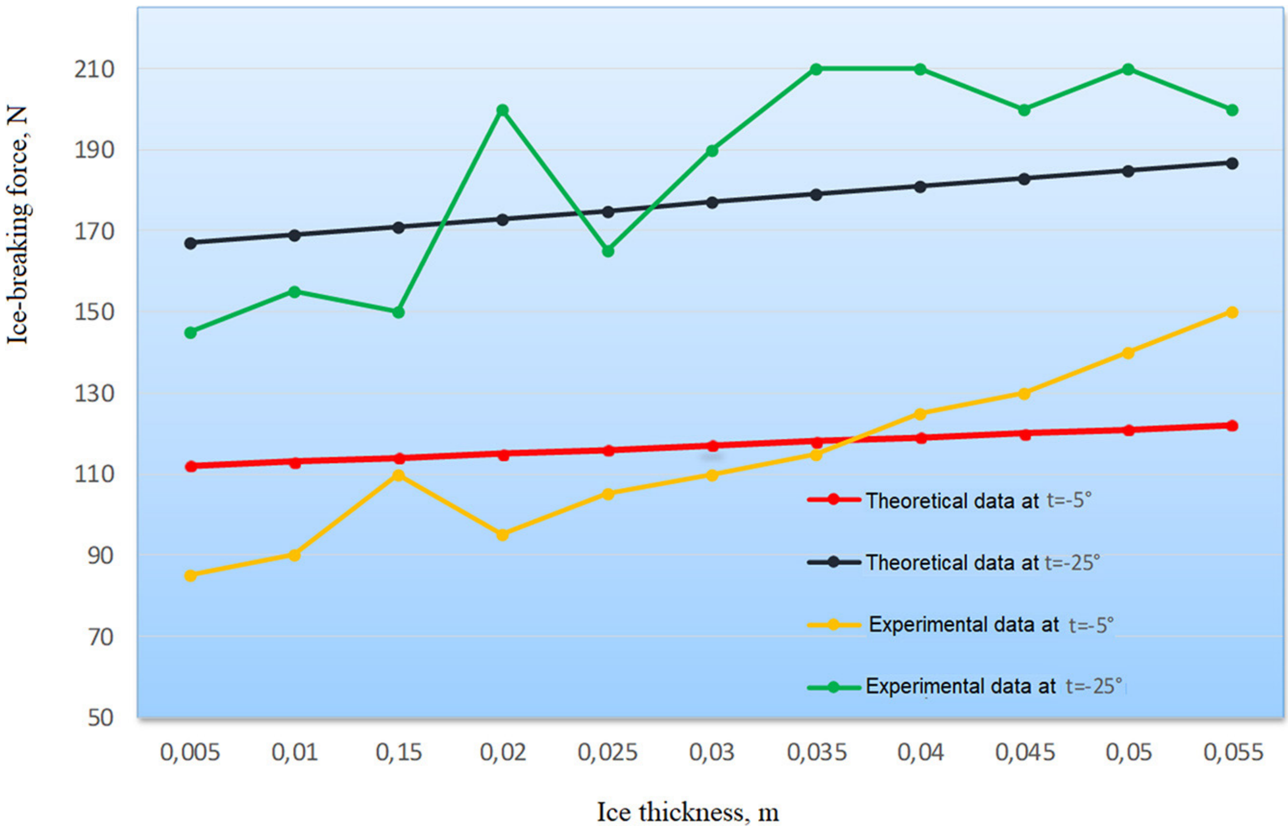

Figure 5 – Change in the dynamic force of ice destruction depending on the thickness of the ice

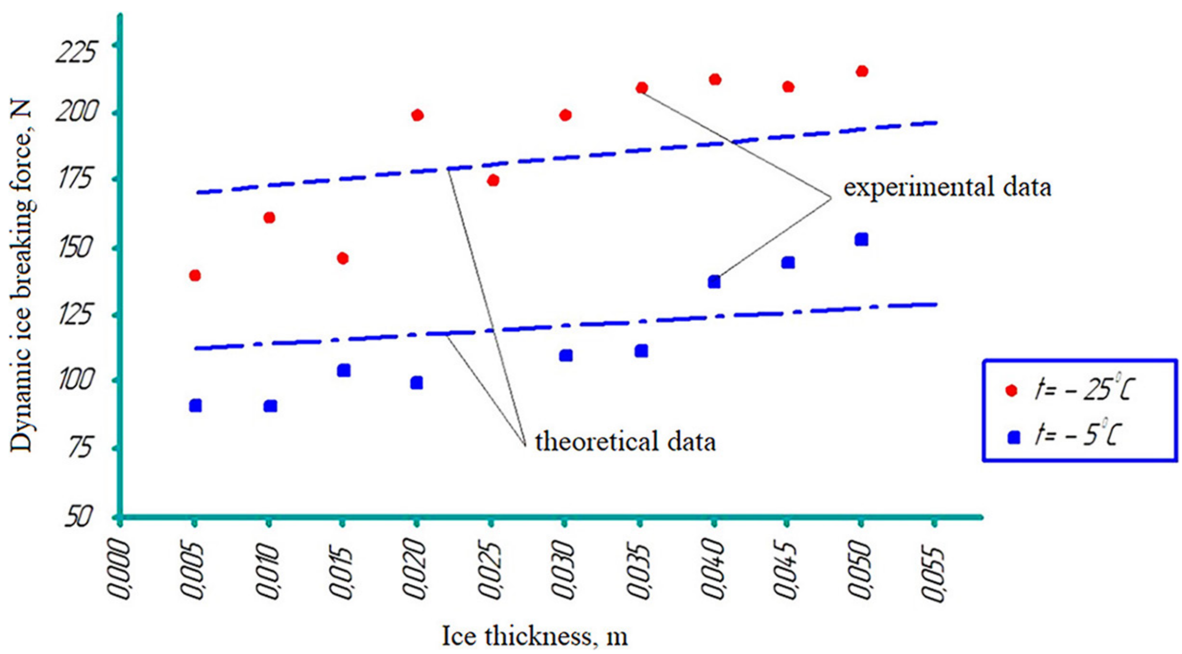

Figure 6 – Comparison of the theoretical and experimental studies

and snow-ice formations from road surfaces and sidewalks.

The obtained mechanical-mathematical models of the interaction of the working bodies of ice-breaking machines with destructible SIF and the corresponding calculation methods will be used in the future in the modernization of existing samples of ice-removing machines, as well as in the development of new promising design solutions.

An effective way to remove ice from roads and sidewalks is its mechanical destruction by impact with a hard cubical surface.

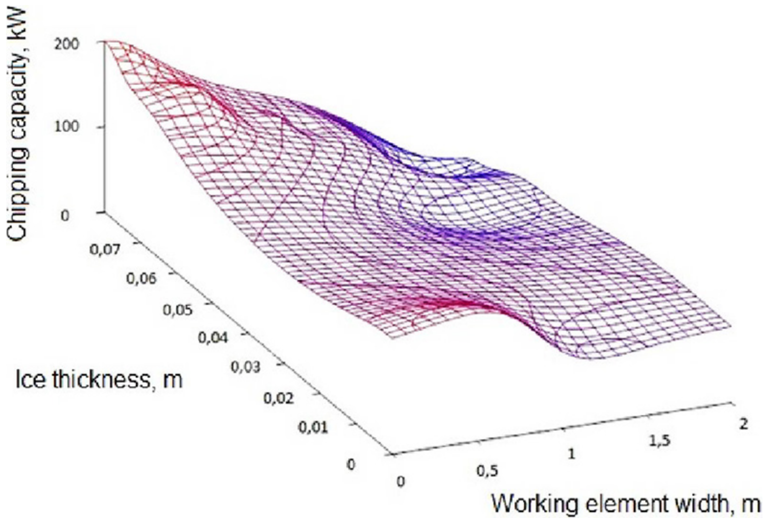

Figure 7 – Dependence of the impact power on the ice thickness and the impactors mass

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Жолдар мен тратуарларды қар мен мұз түзілімдерінен тазарту мақсатында қолданылатын және жол жабдықтарының тиімділігін эксперименттік зерттеу

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Аңдатпа. *Жұмыстың мақсаты – жол төсемінің және тротуардың бетін, олардың тұтастығы мен қауіпсіздігін міндетті түрде сақтай отырып, жұмыс органының параметрлерін және оның жұмыс режимдерін анықтау, онда жол төсемдерінен қар-мұзды түзілімдерді (ҚМТ) тиімді жоюға қол жеткізіледі. Мақалада қар мен мұз қабаттарын жоюға арналған топсалы соққылы-айналмалы жұмыс жабдығының әзірленген жобасы ұсынылған. Ығысу және әсер ету әрекетінің арнайы жұмыс органдарының жобалық параметрлерін есептеу әдістері әзірленді. Мұзды кетіруге арналған жабдықтың әзірленген моделі жобалау кезеңінде де оның ұтым-*

ды механикалық және геометриялық сипаттамаларын реттеу және таңдау арқылы ҚМТ жоюға арналған қондырғының тиімділігін арттыруға мүмкіндік береді. Эксперименттік зерттеулердің талдауы тротуарды тазалау үлгісінің сәйкестігін растады.

Зерттеуді Қазақстан Республикасы Білім және ғылым министрлігінің Ғылым комитеті (грант № AP09258973 «Инновациялық мұз тазалайтын жол жабдықтарын өндірудің жаңа технологиясы») қаржыландырады.

***Кілт сөздер:** қар, мұз, қар және мұз түзілімдері, соққылы мұз жыртқыш, жұмыс органы, тиімділігі, жол, жабын, үлгі, қауіпсіздік.*

Экспериментальные исследования эффективности работы оборудования для борьбы со снежно-ледяными образованиями на дорогах и тротуарах

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***Аннотация.** Цель работы – определение параметров рабочего органа и режимов его работы, при которых достигается наиболее эффективное удаление снежно-ледяных образований (СЛО) с дорожных покрытий, с обязательным соблюдением целостности и сохранности поверхности дорожного покрытия и тротуара. В статье представлена разработанная конструкция навесного ударно-вращательного рабочего оборудования для разрушения снежно-ледяных образований. Разработаны методы расчета конструктивных параметров специальных рабочих органов сдвигового и ударного действия. Разработанная модель ледоуборочного оборудования позволяет еще на стадии проектирования повысить эффективность установки для удаления СЛО за счет регулирования и подбора ее рациональных механических и геометрических характеристик. Анализ экспериментальных исследований подтвердил адекватность модели очистки дорожного покрытия. Актуальность исследования и ожидаемый социальный эффект обосновываются возможностью снижения количества аварий и травм на дорогах Республики Казахстан в зимний период.*

Исследование финансируется Комитетом науки Министерства образования и науки Республики Казахстан (грант № AP09258973 «Новая технология производства инновационного ледоуборочного дорожного оборудования»).

***Ключевые слова:** снег, лед, снежно-ледяные образования, ударный ледоочиститель, рабочий орган, эффективность, дорога, тротуар, модель, безопасность.*

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