AUTOMATED ROAD MILLING CUTTER FOR REPAIR OF THE ROAD SURFACES WITH VARIABLE TRACKAGE

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Resume

The article presents a method of experimental research and created stand with metrological equip-ment that allows to simulate the complex process of milling asphalt concrete samples by force and coordinate closure. As a result of the research, regression equations describing the milling parame-ters of asphalt concrete samples, were obtained. It is established that during the transition from the power (elastic) closure of the technological system to the rigid (coordinate) one, milling errors de-crease by up to 15% and their spread is up to 30%. The developed method for restoring the road surface can be applied in practice not only within Kazakhstan, but outside the country, as well.

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1 Introduction

In the Republic of Kazakhstan, the Law "On Technical Regulation" was adopted, which established that the technical regulation is carried out in accordance with the principles of: application of uniform rules for establishing requirements for products, production processes, operation; unity of rules and methods of research (testing) and measurements during the mandatory conformity assessment procedures. According to this Law, in the current market conditions, the requirements for the parameters of work should mainly be regulated in contracts, mandatory requirements - in national standards.

Over the past 30 years, the equipment has been modified and it is proposed to use new equipment already. These are graders with an automated "Profile" system, self-propelled rollers with a wide range of speed and vibrations, powerful domestic and imported milling cutters, recyclers, automated modern asphalt pavers, asphalt concrete mix loaders, etc. [1-5]. New materials and technologies have appeared with new possibilities for mixing uniformity, laying, with automation of modes. Accordingly, the work requirements and tolerances should be revised, justified and supplemented directly based on conducting the full-scale experimental work on road sections with a secured level of quality of work.

During operation, the road is subjected to various kinds of transport and weather-climatic factors. The very first and most unprotected element experiencing such effects is the asphalt concrete pavement. Practice has established that the main reason that has the greatest influence on the decrease in the quality of the roadway is called excess weight, the flow of cars that form rut, as well as the stressed-deformed state and service life of asphalt concrete pavements of highways depend on increased summer temperatures [6-8].

Wheel formation on roads is one of the main reasons leading to an increase in the degree of risk of road accidents, reduces the comfort and economic efficiency of using roads. The gauge bulges reach 170 mm in height and up to 350 mm in width [9].

Over the past more than twenty years, the road equipment has been modified. Accordingly, the requirements to the road pavement profiling technology, including milling, should be revised, substantiated and supplemented.

The creation of automated road cutters made it possible to significantly easier and more efficiently implement the operations of milling tracks and their spikes as a part of measures to repair roads and ensure road safety [10].

Therefore, the topic of improving the methods of coordinate closure of automated cutters for the repair of track formation of road surfaces is relevant and, therefore, the problem of increasing the efficiency of repair of road surfaces based on the use of coordinate closure of automated road cutters, is urgent.

2 Materials and methods

The long-term urban development plans are inextricably linked with an increase in the pace of construction of residential complexes, individual housing and other socially significant facilities. In development of urban areas, a special role is played by solving a complex of issues on their improvement for comfortable living of the population. At the same time, one of the important tasks is improvement of the sidewalks, courtyard roads and playgrounds, as well as squares, alleys and park areas, require a large number of a wide range of road construction materials.

Currently, concrete pavers of various configurations and asphalt concrete are widely used to solve these problems. However, as practice shows, during the operation of these roads, their destruction is often observed. The fact is that the concrete paving stones are necessarily exposed to the actions of sulphate salts of acids and alkalis, since they are necessarily present in the composition of the soils of the surface being laid and are additionally exposed to the actions of chemical reagents coming from the external environment (rains, car oils, groundwater etc.). Under the influence of these chemicals, concrete pavers and products made on the basis of cement binders are corroded, as a result of which they eventually collapse.

Based on the analysis of the layouts of the existing automated road cutters, the dominant factors determining the change in the mutual position of the working elements of the machine and the road surface in the process of milling the road surface with a variable gauge are determined, which causes a decrease in the evenness of the profiled surface of the road surface [9,11].

As a result of studies, it has been found that the problems of controlling the track milling and its overheads on existing road milling machines come from a lack of feedback, therefore, it is possible to build an adaptive road surface milling system provided that the milling system is supplemented with feedback sensors and appropriate software.

The proposed principle of operation of the software complex of computational modeling makes it possible to determine the recommended height of the removed ramp allowance for the initial conditions of the steady-state mode. Based on that, the numerical modeling of the milling process was carried out.

The possibilities of using the contact sensors are considered, converters of movements into electrical signals, which are usually inductive.

The solution of this problem was proposed to be carried out by changing the structures of the control systems and laws of control of the road milling machines working bodies, as an automated road technological manipulator with several degrees of mobility of a working body - a milling tool operating in generalized technological coordinates for repair of the road surfaces with variable rut and due to the transition from elastic (power) to the rigid (positional or coordinate), as well as the combined closure of the technological system for milling the track and its legs.

At the same time, the need to switch from an elastic (power) closure of the position control circuit to a rigid (coordinate) closure of the track milling process scheme and its overheads is justified, which allows reducing, not only the current average error (deviations from the required level) of milling, but their spread (standard deviation), as well.

3 Results and discussions

At present, when carrying out the repair work to eliminate ruts on road surfaces, the technology of milling outbursts has been used as a temporary measure. When milling outbursts (influx), the required coefficient of adhesion and a smooth surface of the road surface are provided. The problem of precise milling of swells, side bumps next to the track is solved. The milling technology of the track itself does not change [6,9].

Usually, the track is filled with a mixture for patching (cationic emulsion with fine crushed stone, fraction size 5 to 10 mm) or milled to a given depth without requiring accuracy and filled with asphalt concrete mixture followed by compaction. Precise milling is necessary to ensure evenness and ensure road safety. The milling error should not exceed 1 to 3 mm/m.

During the milling, the relative position of the axis of rotation of the milling cutter changes relative to the chassis of the road milling cutter and, accordingly, the road surface, vertical corrective movement is carried out [11-13]. The distance from the cutting line to the axis of rotation of the cutter will be called the level of dimensional adjustment, i.e. during the milling, corrective variable movements are carried out for the vertical position of the cutter.

The cutting line lies at the level of the initial surface of the road surface outside the area, in order to avoid the risk of road traffic accidents (accidents) and to meet the technical requirements of the track repair project. The influx is a mass of asphalt concrete mixture squeezed out of the track to the right or to the left, with different dimensional and mechanical characteristics (height, width, density, shape, strength, presence of cracks, staining, porosity). We will assume that the front and rear wheels of the milling cutter travel on a flat section of road outside the track. The new road construction machines use computer control with drives and working bodies. In addition, additional control circuits can be made independently of the main computer, based on a microcontroller or an industrial computer. The control of the vertical displacement drive will be carried out by adding up the signals coming from the main computer and from the compensation circuit for the deviation of the milling dimensions.

The milling cutter is usually of a Wirtgen (FRG) type design it is recommended to use the free-layout teeth of the milling cutter in the mounting housing to reduce diffusion wear. The freely rotating cutting element is constantly shifted by the heated contact point to the side, outside the contact zone, so the milling cutter section has time to cool down. Therefore, there is no molecular diffusion exchange and the usual mechanical wear is significant for rigid tools are significant.

New road machines use computer control of drives and working organs. In addition, additional control circuits can be implemented independently of the main computer based on the microcontroller or industrial computer. The vertical drive will be controlled by summing the signals from the host computer and the milling size deviation compensation circuit.

A contactless laser sensor is used, the base length is 250 mm, with an error of 0.5 mm of the BOSCH type, which is a housing with an optical eye of the receiving and transmitting system, there is also a microprocessor and an output to computer equipment. The control system sets the setting for the signal received from the sensor, the difference from which this signal gives deviations in the milling dimensions. The feedback control is used with help of correction variables for turning the level of dimensional adjustment of the milling cutter. In fact, it is proposed to switch from kinematic closure by force to kinematic closure by coordinate (displacement or increments of the movements of the milling cutter), because it allows to fully realize the capabilities of the numerical control system of the road milling cutter.

This makes it possible to reduce, not only the current average milling deviation, but their spread, as well (the standard deviation, the square of which is the variance). The task of ensuring only evenness is solved, the task of ensuring the coefficient of adhesion is not set and is not discussed. For traditional constructions of the road milling cutter, power take-off from the main engine or the use of an additional engine is characteristic. In manual control, feedback is implemented through the adaptation of the driver to changing environmental conditions. Previously, kinematic force closure was actually used (by hydro, pneumatic suppression power take-off or by power take-off through auxiliary elements). In fact, this method of controlling the road milling cutter allowed only to prevent or reduce the initial deviation of the treated surface of the road surface during milling. If the size of the allowance and its influx density became larger, then the milling cutter experienced additional vertical loads and additionally deviated upwards from the cutting line, which resulted in deviations in dimensions of the milled surface of the road surface, which led to an increase in the risk of an accident. Changes in the size of these surges can be 10 to 170 mm and will affect the road repair site by 5 to 10 times. Accordingly, the additional vertical component of the cutting force changes at times, caused by a change in the dimensional mechanical parameters of the influx. Therefore, the task arises of compensating for undesirable additional vertical movements of the milling cutter and controlling the level of the milling cutter adjustment in real time.

It is used to set a digital model of the road surface. As an initial information for determining the level of dimensionality of the milling cutter setting, existing milling cutter layouts assume the operation of the milling cutter cutting elements in the milling cutter coordination system, if the interaction occurs through the milling cutter and wheels or, more importantly, through the milling cutter and rollers rolling on the road surface outside the track. In fact, the second method allows milling in the coordinate system of the road surface and without elastic elements in the form of wheels. From the road milling cutters there is only a power take-off. However, this does not allow compensating for the wear of the cutting elements of the cutter, errors in adjustment, temperature deformations. Therefore, the scanning systems determine the digital model of the road surface outside the track and calculate the trajectory of the cutting lines. With respect to this virtual line, automatic or virtual adjustments of tool departures are made so that the tool vertices lie on this calculation line. The adjustment can be done manually.

Previously, the control was carried out according to the instantaneous height - the average value of deviation of the milling dimensions and now we are additionally engaged in reducing the spread of the deviation of the milled surface. For the first time, the precision control of milling of specific elements of the highway is applied - eliminating the influx from the side of the track, the principle of controlling the road milling cutter by feedback is used.

Non-mechanical kinematic connections are widely used in automated road milling cutters. For example, by wires or radio signals. Previously, gears were used. As a rule, new types of drive can work with different types of kinematic closures. For example, by speed, by increment of movements, by moment, by power

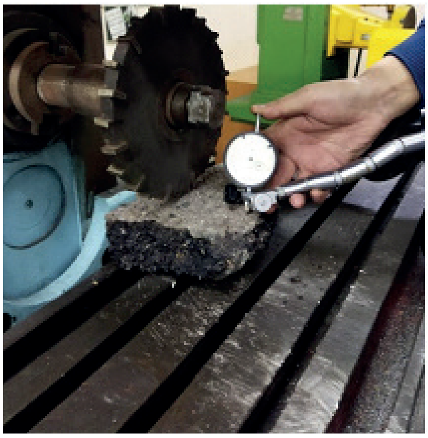


Figure 1 *Procedure for measuring deformations of an asphalt concrete coating sample using a universal magnetic measuring head*

Figure 2 *Measurement of vibroacoustic vibrations during the cutting using a vibration measuring system*

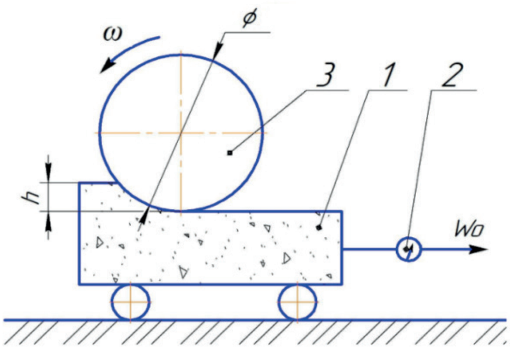


Figure 3*Diagram of the experimental stand for determining the main milling parameters: 1- trolley with a sample of asphalt concrete, 2 - diamond disc, 3 - dynamometer*

(electricity sold). In the work, the control for the increment of movements is selected as the main one. In the non-mechanical kinematic connections, the control principle is important. Control is considered by feedback and by perturbations. The feedback control is selected, which consists in measuring the output parameter, determining the milling deviation, multiplying by the adjustment coefficient and implementing this correcting the variable increment through the vertical displacement drive (correcting variable increment of displacement) of the milling cutter. Comparative simulation tests of cutting asphalt concrete samples with elastic and coordinate closure were carried out. In their formulation, implementation and processing of the results, well-developed and modern methods of experimental research were used. Specifically, the experimental research methodology was developed by Kochetkov [9, 14].

The experimental stand was implemented based on the vertical milling machine in the laboratory of metal-cutting machines. By readjusting it, the axis of rotation of the cutting tool was installed in a horizontal position. As a model of a milling cutter, standard disc cutters with a diameter of 110 and 230 mm (metal-cutting tools) were selected. Photos of the developed stand are shown in Figures 1 and 2.

Figure 1 shows the procedure for measuring deformations of an asphalt concrete coating sample using a universal magnetic measuring head. Figure 2 shows the measurement of vibroacoustic vibrations during cutting using a vibration measuring system. Two series of experiments with elastic and rigid closure were carried out. In the first case, a rubber sheet of a thickness of 5 mm was placed between the magnetic clamping device and the milling machine table. In the second case, the magnetic clamping device was rigidly attached to the milling machine table. A disc milling cutter and a sample of asphalt concrete with an uneven surface were selected. Example, at the real time of the deviation of the milling size consisted of 10 mm, multiply it by the adjustment factor equal to - 0.5, get -5 mm - the value of the variable correction increments and add it to the existing level of dimensional adjustment of the cutter.

This compensates for random changes in the dimensional mechanical parameters of the gauge influx, it also compensates for pressure changes in pneumatic tires, for wear of cutting elements, thermal temperature deformations of the working body and the road milling cutters themselves and compensates for changes in the mass characteristics of the milling cutter. The determined (linear) and periodic (correlating) component of the

***Table 1** Plan and results of experiments*

No.	Plan in natural variables		Feed force W_O (kN)	Residual deformations	
	h (mm)	V (m/s)		rigid fastening	fastening through an elastic element
1	10	0.03	3.8	1.8	1.6
2	60	0.03	20.6	2.8	2.4
3	10	0.05	4.2	2.0	1.7
4	60	0.05	22.7	2.1	1.5
5	7.68	0.04	2.6	1.7	2.4
6	77.68	0.04	26.2	2.8	4.6
7	35	0.023	11.2	2.1	3.0
8	35	0.047	13.1	2.2	3.1
9	35	0.04	11.7	2.6	3.1
10-13	35	0.04	12.0	2.7	3.3

milling deviation sequence is actually compensated. The random component cannot be controlled.

Comparative simulation tests of the cutting asphalt concrete samples with elastic and coordinate closure were carried out. A methodology for study of the main parameters of milling has been developed. The research was aimed at determining the relationship between the milling depth (h) and the disk feed rate (V) on the feed resistance (Wo). The experiments were carried out on a specially made stand (Figure 3).

The rotation frequency of the disk was taken as a constant in the experiments, which provided a linear cutting speed of up to 50 m/s. At the same time, the feed rate of the diamond disc varied from 1.8 m/min to 3 m/min and the milling depth h - from 10 to 60 mm. The experiments were carried out with 3-fold repetition, in accordance with the developed plan of the factor experiment presented in Table 1 with the results of the experiments.

The scientific result is registering the fact of an increase in the spread of residual cutting deformations (errors) in comparison of rigid and elastic force closures [9, 14-15]. After the processing of the experimental results, mathematical dependences were obtained (the feed effort of the W_O on the milling depth h and the feed speed V)

$$W_O = 0.35h + 0.1h \cdot B\,. \tag{1}$$

Based on this dependence, the average value of the milling resistance was determined, q_O as

$$q_O = W_O / h \cdot B\,, \tag{2}$$

where B is the milling width. The q_O values are 60 to 80 kPa and can be used to determine the drive power N

$$N = 0.5 \cdot q_O \cdot h \cdot B \cdot D \cdot \omega\,, \tag{3}$$

where D - is the diameter of the disk, ω - is the angular velocity of rotation of the disk.

The experimental stand is implemented based on the horizontal milling machine 6M82G. At the same time, the task was to reproduce the process of interaction between the milling tools and asphalt concrete as close as possible to the real one. As a model of the drum of the road milling cutter, a prefabricated milling cutter with a ratio of diameter and width similar to the working bodies of existing machines was chosen. The milling cutter was assembled from a typical metal-cutting tool, taking into account the peculiarities of asphalt concrete processing, discs with a large tooth were selected to reproduce the effect of dyeing (breaking out) and not cutting the sample.

Two series of experiments with elastic and rigid closure were carried out. Milling was carried out towards the treated surface (against the feed). Two modes were investigated: - with an elastic element (rubber base with a thickness of 20 mm) (Figure 4 a, b) - simulation of milling by force closure. The sample was fixed on a specially designed experimental table mounted on the frame through an elastic element. In this case, there was an increased spread of deviations of milling parameters and an increase in the average height of the profile of the milled surface - in the case when the sample with asphalt concrete was fixed rigidly (Figure 4 c, d) - imitation of coordinate closure, a decrease in deviation of the milling dimensions was observed, according to approximate estimates, by 2 times. This confirms the effectiveness of the transition from force closure to coordinate closure or displacement control. Photos of part of the experiments are shown in Figure 4.

Outside of the experimental plan, the milling of an asphalt concrete sample was carried out by force closure using springs of variable stiffness as elastic elements, simulating different stiffness of the milling cutter - tool-coating system. The observation showed that the effect of the rigidity of the milling cutter - tool-coating system on the deviation of the milling profile is not linear and

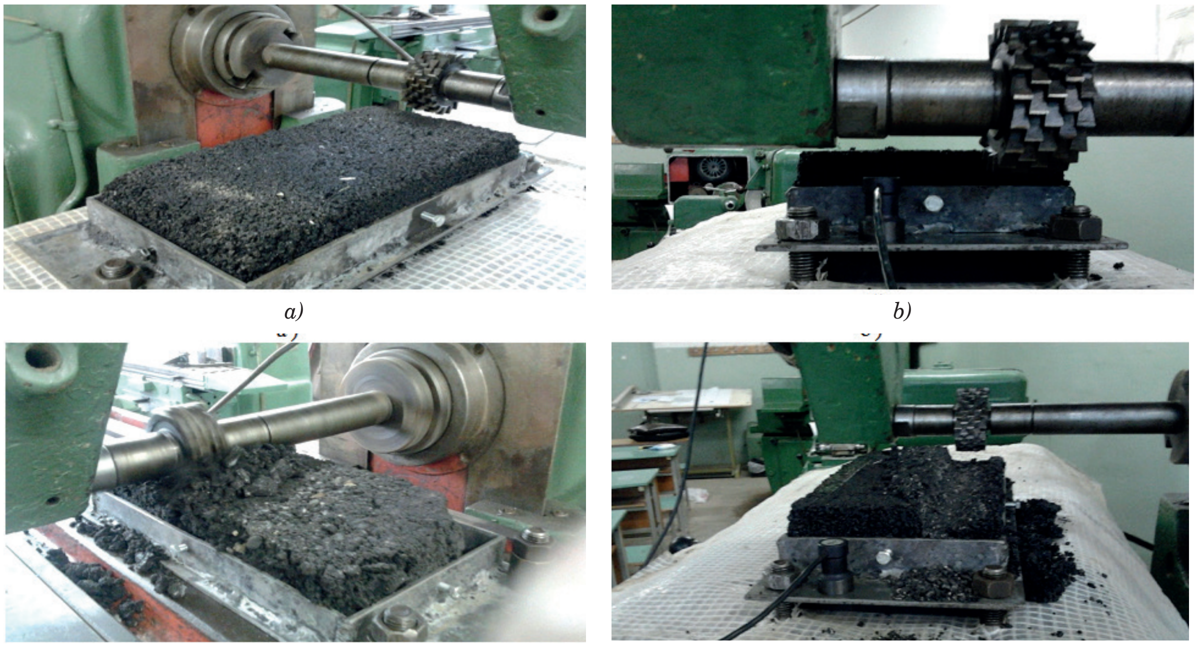
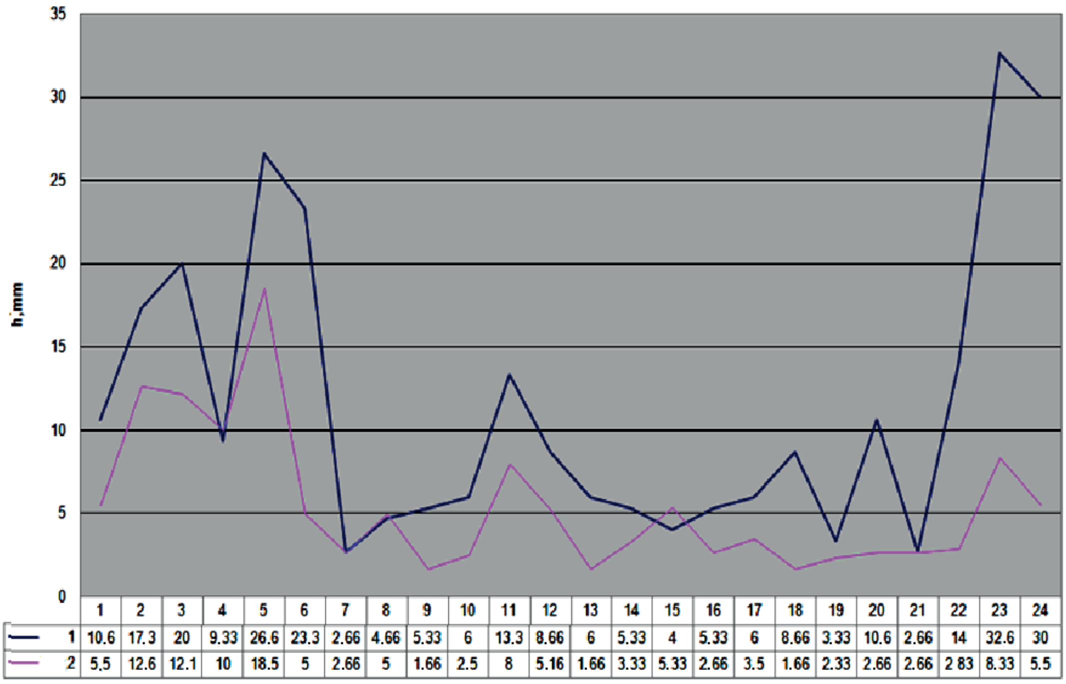


Figure 4 *Experiment on simulation milling of asphalt concrete samples:*
a)with elastic element (rubber base 20 mm thick); b) simulation of milling by power closure;
c) the sample with asphalt concrete was fixed rigidly; d) imitation of coordinate closure



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	10.6	17.3	20	9.33	26.6	23.3	2.66	4.66	5.33	6	13.3	8.66	6	5.33	4	5.33	6	8.66	3.33	10.6	2.66	14	32.6	30
2	5.5	12.6	12.1	10	18.5	5	2.66	5	1.66	2.5	8	5.16	1.66	3.33	5.33	2.66	3.5	1.66	2.33	2.66	2.66	2 83	8.33	5.5

Figure 5 *Comparison of results of the road surface milling with use of the road cutters:*
- elastic closure, - rigid closure

increases abruptly with a decrease in the rigidity of the system (an increase in its elasticity).

It is possible to use the developed algorithms of adaptive sign and proportional adjustments. As a result of modeling based on the initial sample, a decrease in the average value of the milled surface of the protrusions by 20% was obtained when using sign pulsating adjustments with a variable pulse. Comparison of the results of milling asphalt concrete pavement with use of the road cutters for elastic (power) and rigid (coordinate) closure is shown in Figure 5.

The technological scheme of milling of the first track of the road surface has been developed, the effectiveness of the rigid (coordinate) closure of the technological scheme of milling in comparison to the elastic (force) method has been confirmed.

Practical results of the study of methods of automated road milling control were obtained. It is obtained that during the motion control (coordinate closure) there is a decrease in the residual deformation spread compared to the elastic closure control.

The use of results of this work would allow for more efficient work on construction, repair and maintenance of highways, to ensure the required transport and operational characteristics, the safety of highways and road safety.

4 Conclusions

Based on the analysis of the layouts of existing automated road cutters, the dominant factors determining the change in the relative position of the working bodies of the machine and the road surface, during the milling of the road surface with variable track height are determined, which causes a decrease in the evenness of the profiled surface of the road surface.

The concept of presenting a road milling cutter as an automated road transport and technological manipulator that corrects the level of dimensional adjustment by vertical movements of the working body is proposed, based on of which a new design of an automated road milling cutter, for repairing road surfaces with variable trackage with the possibility of adjusting the working body in height, has been developed.

The feasibility of the transition from elastic (force) closure to rigid (coordinate-kinematic) closure of the track milling process scheme has been substantiated and proved, which allows not only to reduce the current average deviations of the height of the milled surfaces, but their variations from the average, as well.

The transition to coordinate and kinematic closure makes it easier, both from the point of view of building a drive system and from the point of view of programming processes, to implement the process of operation of automated road cutters.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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