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Satbayev University

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ИЗВЕСТИЯ

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РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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INCREASING THE EFFICIENCY OF MOTOR GRADERS WORK ON THE BASIS OF WORKING ELEMENTS PERFECTION

Abstract. The research considers methods of motor graders rise of efficiency by perfecting constructions of cutting elements and working organs on the basis of rise of a resource of their work.

The work contains a research of interdependence of parameters of motor graders working organs by statistical methods with the purpose of detection of the basic tendencies of their development. The basic directions of designing of motor graders working organs and most perspective constructions are detected by a method of analysis of patent solutions. The formulas for account of resistance of ground to cutting by a knife with one direct and two sloping cutting edges with allowance for an angle of declination of a knife and its wear are deduced. The regularities of a wear of the cutting elements of a blade are investigated, its influence to efficiency of work and on parameters of working organs design is detected. The maximum size of wear is determined.

The requirements to motor graders working equipment are defined on the basis of conducted researches, the new constructions of multiple use knives and order of their sequential replacement are developed in correspondence with the research work. It ensures the raise of efficiency of the machine by 10…15 per cent and it increases resource of knives in comparison with a traditional construction 3…4 times as much.

Key words: grader, cutting element, wear, soil, blade, cutting, working body.

Introduction. Earthworks in the total volume of construction have a significant share. Over 15 billion m^3 of earthworks is carried out annually in the CIS, including over 800 million m^3 in the Republic of Kazakhstan.

Studies [1,2] have shown that 70...80% of the ETM fleet, including motor graders, work with unacceptably worn-out CE. At the same time, the performance of motor graders is provided by the engine power reserve, although they operate in an economically unprofitable mode, with an excess load on components and parts in comparison with the optimal one, with an increase in fuel consumption, which ultimately increases the cost of soil development.

The wear allowed in practice of the CE ETM causes an increase in the cutting force by 3...4 times, the energy intensity of the cutting process by 1,4...3 times, the cost of soil development by 8...15% with a decrease in productivity by 10...30%. This leads to an increase in the stress state of the entire machine and reduces its operational reliability. Excessive wear of the CE leads to the economic impracticability or practical impossibility of further operation of the machines.

The above-mentioned intensive wear of CE ETM [6], which leads to an increase in the energy intensity of ground cutting, requires frequent replacement, in which most of the expensive scarce metal goes to scrap. Therefore, one of the main ways to improve the efficiency of ETM is to improve CE structures by reducing their metal consumption by making the wear part of the tool removable, reducing the energy consumption of the cutting process and increasing the wear resistance.

The above-mentioned areas of research on the productive use of machines, identification and creation of promising designs of working bodies have determined the task of further improving the efficiency of motor graders by improving the working elements, taking into account their wear resistance, and this determines the relevance of the work.

Methods. Theoretical research has been carried out to identify the most significant parameters of the working bodies of motor graders by the method of correlation analysis.

By processing an information databank on a PC which includes more than 5600 parameter values of 282 grader models, the following results are obtained:

– pair correlation equations are derived, while the main parameter is the power of the installed engine, which is most correlated with the other parameters;

– a regression equation is obtained that relates seven parameters of the blade [8], changing simultaneously, with the engine power:

$$N = -1.84 \cdot 10^{-11} + 1.21 \cdot 10^{-15} Bo - 1.27 \cdot 10^{-16} Ho - 1.81 \cdot 10^{-15} Hz + \\ +4.67 \cdot 10^{-14} Hr - 4.92 \cdot 10^{-16} Zv + 0.002 Po - 1.26 \cdot 10^{-15} C. \quad (1)$$

The obtained regression equations showed that from the studied parameters of the damp, the decisive factor is the force pressing the blade (force in the hydraulic cylinders of the blade), i.e. force providing cutting of the ground, the value of which is closely related to the wear of the CE.

This confirms the importance of studying the patterns of CE wear and their use in the design and operation of dumps.

The results of the analysis of patent information on CE of motor graders are considered. A morphological classification of patent information was developed [3], which allowed it to be systematized.

A PC was used to process the patent information collected and systematized by the classifier, in particular to obtain regression equations to determine the rate of patenting for each classification feature.

Based on the processing of information arrays, mathematical models of patenting dynamics for motor grader knives, the method and structures of their attachment are obtained, which are shown in table 1, which allow us to identify the main trends in improving the working bodies of motor graders and their prospects, as well as the prospects and significance of individual design solutions.

Table 1 – Mathematical models of the dynamics of patenting motor grader knives, methods and structures of their attachment (according to morphological classification

Cipher	Classification features	Code	Regression equation
P_1	For the purpose of knives	1	$N_i = \exp[0.347 + 0.028(t - 87.500)]$
P_2	By the shape of the knife	2	$N_i = \exp[0.396 + 0.037(t - 88.286)]$
P_3	By the profile of the knife	3	$N_i = \exp[0.719 + 0.093(t - 88.667)]$
P_4	The rows of fastening of the knife	4	$N_i = \exp[0.358 + 0.124(t - 88.600)]$
P_5	By the number of cutting edges	5	$N_i = \exp[0.914 + 0.102(t - 88.286)]$
P_6	By the location of the cutting edges	6	$N_i = \exp[0.783 + 0.101(t - 87.000)]$
P_7	By the shape of the cutting edges	7	$N_i = \exp[0.099 + 0.030(t - 87.857)]$
P_8	Increased wear resistance, durability, rigidity, reliability	8	$N_i = \exp[1.090 + 0.129(t - 88.091)]$
P_9	By the method of fastening the knife	9	$N_i = \exp[0.896 + 0.028(t - 87.250)]$
P_{10}	By the shape of the bolt heads	10	$N_i = \exp[0.173 + 0.044(t - 86.875)]$
P_{11}	By bolt bar shape	11	$N_i = \exp[0.497 - 0.079(t - 90.000)]$
P_{12}	By the shape of the holes on the knife and base plate	12	$N_i = \exp[0.717 - 0.070(t - 89.000)]$
P_{13}	By the design of the tightening elements	13	$N_i = \exp[1.169 - 0.049(t - 87.833)]$
P_{14}	Digging process intensifiers	14	$N_i = \exp[0.277 + 0.078(t - 89.400)]$

It is established that one of the most promising directions in the design of dump knives is their multiple use, i.e. execution of several cutting edges on one knife [7.9].

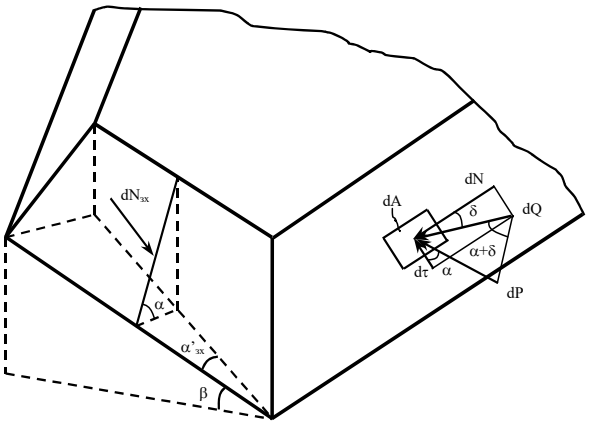


Figure 1 – Diagram of forces acting on the working cutting edges of the knife

Results. One of the most significant design solutions is a rectangular knife with four cutting edges. This design is taken as a basis for further improvement. The development of this direction is possible by using polygonal knives with more than four edges.

Theoretical developments of the main stages of ground cutting with reusable polygonal knives are considered, taking into account the possibility of simultaneous direct and oblique cutting with three or two adjacent cutting edges. A diagram of the knife operation is shown in figure 1, and on its basis formulas are derived that allow to characterize the change in the ground resistance to cutting depending on a number of factors that can affect the design of the CE blade, i.e. its knives.

It is established that the main parameter influencing the resistance of the ground to cutting by knives [4,5], which make up the cutting part of the motor grader blade, is the angle of capture of the side working face of the knife α'_{zh}, depending on its design.

The highest efficiency of cutting soil in a straight position of the damp (when its capture angle $\delta_{zh}=90^0$) corresponds to the capture angles of the side working face of the knife $\alpha'_{zh}=25\ldots35^0$.

The angle of inclination of the knife β also affects the amount of ground resistance to cutting. As it grows, this value decreases. However, the β parameter is not constructive, but depends on the technology of the motor grader.

A formula is derived for calculating the resistance P of the soil to cutting with a knife with one straight and two inclined cutting edges, taking into account the angle of the knife. A formula is also obtained for calculating the coefficient of reducing the cutting resistance of the soil when using such a knife in comparison with the work of one straight edge.

A formula is derived for calculating the resistance of the soil to cutting with a knife, taking into account its wear:

$$P_{Pk}=B_n\cdot\left[(h-S)\cdot\left(1+f\cdot\sqrt{\frac{1}{\sin^2\alpha}-1}\right)+\frac{r}{\cos45^0}\cdot\left(1+f\times\sqrt{\frac{1}{\sin^2(\varphi+45^0)}-1}\right)+a\cdot\left(1+f\cdot\sqrt{\frac{1}{\sin^2\varphi}-1}\right)\right]\times$$

$$\times\frac{1-\sin\rho\cdot\cos2\varphi_n}{1+\sin\rho\cdot\cos2\varphi_n}\left\{3\cdot C_o\cdot\cos\rho+\gamma_n\cdot\left[\frac{h-S}{2}+\frac{r\cdot\sin(\varphi+45^0)}{2\cdot\cos45^0}+\frac{a\cdot\sin\varphi}{2}\right]\right\}+2\cdot\left[K_z\cdot B_k\cdot h\cdot\mu+\varepsilon\cdot B_k\cdot h\cdot\mu\cdot\upsilon^2\right], \quad (2)$$

which shows that the formation of wear areas significantly increases the cutting resistance. However, in order to use this formula effectively, it is necessary to study the patterns of blade wear.

The width of the knife and its edges primarily affect the ability to regulate the process of working off the blade, in particular, the process of its wear. Production observations were made that showed uneven wear of the dumb blade along the length. A method of sequential change of the most worn-out sections of the blade is proposed. The width of the knives should ensure the most optimal division of the blade into such sections. In this case, the criterion is the cost of working out knives. It is established that the optimal number of knives on the blade corresponds to 20...25. Accordingly, the width of the knife edge should be within 120...150 mm, and the ratio of the width of the main working edge and the width of the side working edge of the knife $B_k/B_n=0.4..0.6$.

To the geometrical elements of wear of the blade of the wedge profile include: the blunting area «*a*», oriented at a negative angle «*φ*» to the cutting plane and the rounding of the front edge of the blade, characterized by a radius «*r*». In various specific cases, any of these elements can be of decisive importance. Identifying the significance of each of them and establishing its critical values is an extremely difficult task, which, along with this, does not make it possible to obtain sufficiently reliable results due to the multi-planned process of cutting soil and a large number of random factors affecting it. Therefore, the complex dimension «*S*», including all of the above, was taken as the defining wear element.

The study of the regularities of changes in the geometric wear elements that form the reduced size «*S*» had two goals:

1. Establish their relationship and on this basis derive the minimum number of formulas that characterize the given size and are convenient for practical use;

2. Determine the impact of CE wear on the efficiency of cutting the ground and identify the maximum permissible amount of CE during the operation of the motor grader.

$$S = bc + cd + de = r \cdot \cos\alpha + r \cdot \cos\varphi + a \cdot \sin\varphi \text{ or } S = r(\cos\alpha + \cos\varphi) + a \cdot \sin\varphi. \quad (3)$$

As a result of production tests, regularities of changes in geometric parameters of wear of motor grader dumps in various soils were established. The corresponding equations are obtained.

Taking into account the established dependencies, formula (3) for the most common soils of the Republic of Kazakhstan can be transformed as follows:

– for sandy loam:

$$S = (2.7 + 0.026V)(2.13 + \cos\alpha), \quad (4)$$

– for clay-containing soils:

$$S = (2.7 + 0.030V)(1.66 + \cos\alpha). \quad (5)$$

The results of calculations using the obtained formulas give satisfactory convergence with the results of measurements.

On the basis of the carried out experiments, the dependences of the wear elements «*r*» and «*a*» on «*S*» were also obtained, which made it possible to clarify and concretize the General formulas for determining the forces of ground resistance to cutting. The calculation showed a significant impact of wear growth on the increase in ground cutting resistance (figure 2).

Comparison of the regularities of changes in the reduced size «*S*» and performance of motor graders showed their close relationship. It was found that an increase in the given size to the value $S = 30mm$ causes a decrease in productivity in soils of categories II and III by more than two times. At the same time, as mentioned above, most dumps are operated with significant wear of the knives, i.e. the greatest amount of ground is produced by heavily worn blades.

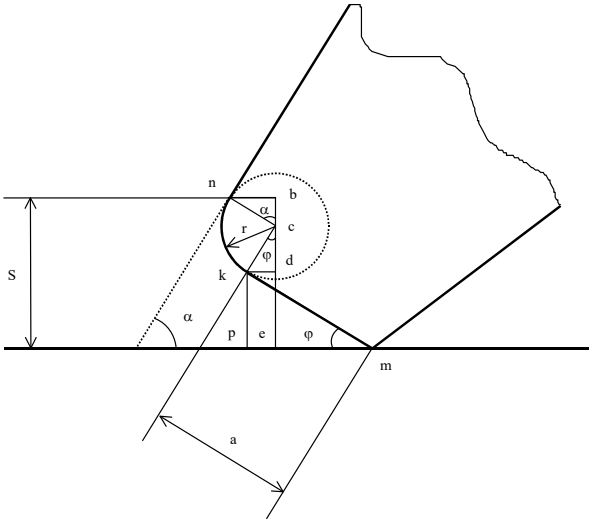
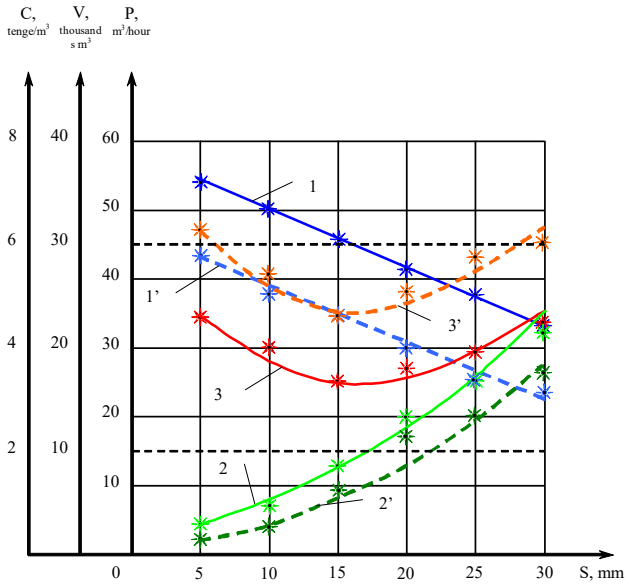


Figure 2 – Geometric diagram for determining the reduced size of wear

The study of changes in the cost of soil development depending on the value of the reduced size of the blade wear «*S*» and the amount of ground running at the corresponding wear showed that there are values of «*S*» corresponding to the minimum cost. Acceptance of such values as the maximum permissible will optimize the workflow of motor graders.



1 – productivity in the development of soils of the II category;
1' – productivity in the development of soils of the III category;
2 – operating time for category II soils;
2' – operating time for category III soils;
3 – the cost of developing category II soils;
3' – the cost of developing category III soils.

Figure 3 – Dependence of changes in productivity, operating time and cost of development in soils of categories II and III from the given size of bluntness

Figure 3 shows graphs of the above dependencies for soils of category II and III. It is seen that the cost curves have a well-defined extremum corresponding to the minimum value $S \approx 15 mm$. The obtained data show that it is advisable to take $S = 15 mm$ as the criterion for working out the blade, allowing in some cases excess of wear to $S = 18...20 mm$.

However, it was necessary to clarify the value of the maximum blunting of such a knife. Subsequent production experiments during comparative tests made it possible to establish that this value corresponds to the values previously set for standard knives: $S = 15...20 mm$.

That hexagonal knives, as well as knives of other polyhedral shapes, cannot be used as side knives of the blade, if the nature of the work requires its inclined position with an angle of inclination $\gamma > 5^0$. Here you need to use knives that have a side edge perpendicular to the working edge. Therefore, in this case, «K»-shaped knives are proposed as side knives.

On the basis of hexagonal and«K»-shaped knives, three designs of the cutting part of the grader blade were developed (figure 4):

- with hexagonal knives fixed on the blade in two rows. The design provides a continuous blade and is recommended for planning work with a horizontal blade (figure 4, a).

- with hexagonal knives fixed on the blade in two rows as medium and large «K»-shaped knives. The design provides a continuous blade and is recommended for cutting soil at any inclination of the blade (figure 4, b).

- with hexagonal, triangular and "K"-shaped knives arranged in a single row. The design provides a continuous blade and is recommended for cutting soil at any inclination of the blade (figure 4, c).

The tests were carried out according to the developed methodology based on the use of a nomo-gram of step-by-step testing of reusable knife blades, the construction of which is possible on the basis of a reduced amount of experimental data.

Three designs of the cutting part of the dumps were investigated – with standard knives, with four-sided knives, and with hexagonal knives arranged in two rows.

For these designs of the cutting part of the blade, two ways of replacing the worn blade were studied: standard (parallel)-when the entire blade is replaced, and sequential - by replacing the blade sections sequentially along the blade zones.

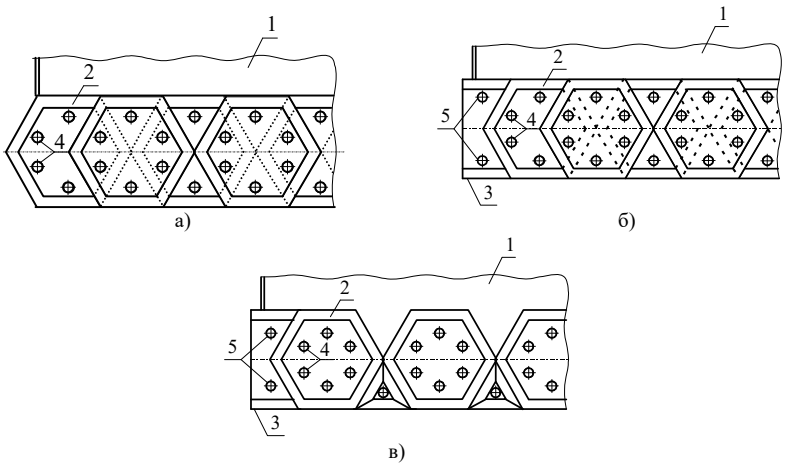
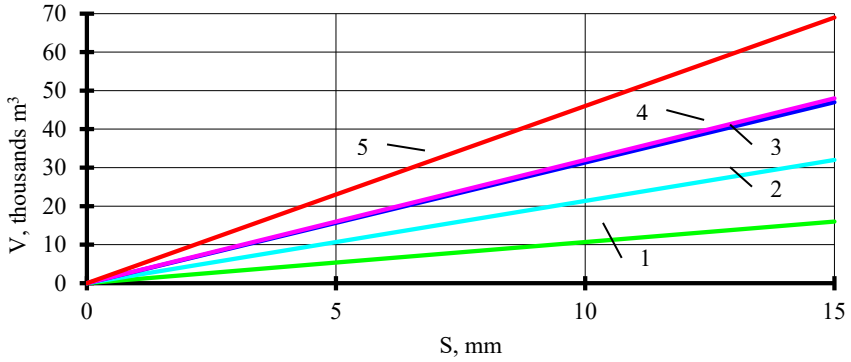


Figure 4 – Versions of the cutting part of the motor grader blade

As a result of comparative tests, data were obtained showing that hexagonal knives with sequential changes provide an increase in productivity by 10 ... 15% compared to standard knives. The resource of knives increases even more significantly. Figure 5 shows graphs of the dependence of the volume of the developed soil on the given size of wear, obtained for the tested knife designs.



1 - standard knives; 2 - four-sided knives in a parallel change; 3 - tetrahedral knives with sequential change; 4 - hexagonal knives for parallel change; 5 - hexagonal knives with sequential chang

Figure 5 – Graph of the dependence of the volume

It is seen that compared with the standard design of the cutting blade structure with tetrahedral and hexagonal knives increase the soil production with the adopted parallel blade 2 and 3 times, and with the proposed sequential change – 3 and 4.3 times accordingly.

It is established that the main influence on the engine power from the parameters of the working body is the force of pressing the blade to the ground. The largest part of the rated power is spent on providing this power. And the fact that the force of pressing the blade depends on the ground resistance to cutting associated with the design and blunting of the re, proves the importance of studying the influence of the design of knives and their wear patterns in order to improve the design of the cutting part of the blade and develop optimal modes of their development.

Conclusion. The most significant and promising structures are identified. One of them - square knives with four cutting blades, the alternation of which increases the life of the knives - is taken as the base for improvement in the direction of increasing the number of cutting edges. Thus, it is established that the new knife must have the shape of a polygonal plate with more than four edges.

Comparative tests of dumps with the cutting part of three designs – with standard knives, with four-sided knives and with hexagonal knives arranged in two rows were carried out. The obtained results showed the advantage of the cutting part with hexagonal knives, worked out according to the proposed method of successive replacement of worn knives: its productivity is higher by 10...15%, the average resource is 4 times higher than that of the standard cutting part. And in comparison with tetrahedral knives, the resource is 1.5 times higher.

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ЖҰМЫС ЭЛЕМЕНТТЕРІН ЖЕТІЛДІРУ НЕГІЗІНДЕ АВТОГРЕЙДЕРЛЕРДІҢ ЖҰМЫС ТИІМДІЛІГІН ЖОҒАРЫЛАТУ

Аннотация. Зерттеу автогрейдерлердің тиімділігін олардың жұмыс ресурсын арттыру негізінде кесу элементтері мен жұмыс органдарының конструкцияларын жетілдіру арқылы арттыру әдістерін қарастырады.

Автогрейдерлердің жұмыс органдарының параметрлерінің олардың дамуының негізгі тенденцияларын анықтау үшін статистикалық әдістермен өзара тәуелділігін зерттеуді қамтиды.

Патенттік шешімдерді талдау әдісімен автогрейдерлердің жұмыс органдарын және неғұрлым перспективалы конструкцияларды жобалаудың негізгі бағыттары анықталды. Пышақтың көлбеу бұрышы мен оның тозуын ескере отырып, бір түзу және екі көлбеу кесу жиектері бар пышақпен кесуге топырақтың қарсылығын ескеру формулалары көрсетілген. Пышақтың кесу элементтерінің тозу заңдылықтары зерттелді, оның жұмыс тиімділігі мен жұмыс органдарының құрылымдық параметрлеріне әсері анықталды. Тозудың максималды мөлшері анықталады.

Алынған нәтижелер алтықырлы пышағы бар қайырма күректің келесідей артықшылығын көрсетті: олардың өнімділігі стандартты пышағы бар қайырма күректерден 10...15% жоғары, ал ресурсы стандартты 4 есе жоғары және төртқырлы пышағы барынан 1,5 есе жоғары.

Түйін сөздер: автогрейдер, кескіш элемент, тозу, топырақ, қайырма күрек, кесу, жұмысшы орган.

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ПОВЫШЕНИЕ ЭФФЕКТИВНОСТИ РАБОТЫ АВТОГРЕЙДЕРОВ НА ОСНОВЕ СОВЕРШЕНСТВОВАНИЯ РАБОЧИХ ЭЛЕМЕНТОВ

Аннотация. В исследовании рассматриваются методы повышения эффективности автогрейдеров путем совершенствования конструкций режущих элементов и рабочих органов на основе повышения ресурса их работы.

Работа содержит исследование взаимозависимости параметров рабочих органов автогрейдеров статистическими методами с целью выявления основных тенденций их развития. Методом анализа патентных решений выявлены основные направления проектирования рабочих органов автогрейдеров и наиболее перспективных конструкций. Выведены формулы для учета сопротивления грунта резанию ножом с одной прямой и двумя наклонными режущими кромками с учетом угла наклона ножа и его износа. Исследованы закономерности износа режущих элементов лезвия, выявлено его влияние на эффективность работы и на параметры конструкции рабочих органов. Определяется максимальный размер износа.

На основе проведенных исследований определены требования к рабочему оборудованию автогрейдеров, разработаны новые конструкции ножей многократного использования и порядок их последовательной замены в соответствии с научно-исследовательской работой. Это обеспечивает повышение КПД станка на 10...15% и увеличивает ресурс ножей по сравнению с традиционной конструкцией в 3...4 раза.

Ключевые слова: автогрейдер, режущий элемент, износ, грунт, отвал, резания, рабочий орган.

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