ISSN 0798 1015

REVISTA ESPACIOS

Vol. 39 (Number 18) Year 2018 • Page 29

Some approaches to solving problems of increasing the level of machinery reliability

Algunos enfoques para resolver los problemas de aumentar el nivel de fiabilidad de las máquinas

ZHANDARBEKOVA Assel 1; SARZHANOV Dauren 2; MURZABEKOVA Kenzhegul 3; TULENDIEV Erlan 4

Received: 20/01/2018 • Approved: 15/02/2018

Contents

ABSTRACT

Relevance. In modern conditions, the world market puts ever more stringent requirements for engineering products. Practice shows that the market economy forces to create more and more perfect models of machines by selecting a small number of best models and further improving from the viewpoint of reducing downtime in repairs. In this regard, the relevance of this work is due to the need to maintain the required level of reliability of machines at the optimal level of costs for operating repair of assemblies.
Objective: Reducing the minimum total unit costs for maintaining the reliability of machines in operation.
Research tasks: By computer modeling, determine the boundaries of the optimal increase in the reliability of frequently failing transmission parts and assemblies of single-bucket front loaders.
Object of study: Parts and subassemblies limiting the reliability of the hydro-mechanical drivetrain transmission of the L-34B, 534C single-bucket front loaders.
Research design. The methods of the theory of reliability of technical systems, the theory of the restoration of the operability of repaired products and the methods of computer simulation of machine reliability indicators are applied to the processes of

RESUMEN

Pertinencia. En condiciones modernas, el mercado mundial exige requisitos cada vez más estrictos para los productos de ingeniería. La práctica muestra que la economía de mercado obliga a crear modelos de máquinas cada vez más perfectos seleccionando un pequeño número de mejores modelos y mejorando aún más desde el punto de vista de reducir el tiempo de inactividad en las reparaciones. En este sentido, la relevancia de este trabajo se debe a la necesidad de mantener el nivel requerido de confiabilidad de las máquinas al nivel óptimo de costos para la reparación operativa de ensamblajes. **Objetivo:** Reducir los costos unitarios totales mínimos para mantener la confiabilidad de las máquinas en operación. **Tareas de investigación**: mediante el modelado por computadora, determine los límites del aumento óptimo en la confiabilidad de piezas y conjuntos de transmisión que fallan con frecuencia en los cargadores frontales de un solo cucharón. **Objeto de estudio**: Partes y subconjuntos que limitan la confiabilidad de la transmisión hidromecánica del tren motriz de los cargadores frontales de cuchara única L-34B, 534C. **Diseño de la investigación**. Los métodos de la teoría de confiabilidad de sistemas técnicos, la teoría de la restauración de la operabilidad de productos reparados y los métodos de

restoring the operability of parts and assemblies according to the basic theoretical laws.
Results. The parameters for the distribution of failures of subassemblies and parts that limit the reliability of the object of research are determined. The boundaries of the optimum increase in reliability indicators of frequently failing parts and SB-165-2 transmission components are revealed. It has been established that for the least reliable groups of parts of the SB 165-2 transmission, the durability can be increased in the range 2.0–2.5. To increase the reliability of the assembly under consideration, it is proposed to reduce the number of operating repairs by issuing recommendations for improving the reliability of the least reliable, unreliable and insufficiently reliable groups of parts for joint replacements.
Keywords: reliability theory, operational reliability, single-bucket front loader, transmission, operating repair.

simulación computarizada de indicadores de confiabilidad de la máquina se aplican a los procesos de restauración de la operatividad de piezas y ensamblajes de acuerdo con la teoría básica leyes
Resultados. Se determinan los parámetros para la distribución de fallas de subconjuntos y partes que limitan la confiabilidad del objeto de investigación. Se revelan los límites del aumento óptimo en los indicadores de confiabilidad de las piezas con falla frecuente y los componentes de transmisión del SB-165-2. Se ha establecido que para los grupos de partes menos confiables de la transmisión SB 165-2, la durabilidad puede aumentarse en el rango 2.0-2.5. Para aumentar la fiabilidad del conjunto considerado, se propone reducir el número de reparaciones operativas emitiendo recomendaciones para mejorar la confiabilidad de los grupos de piezas menos confiables, poco confiables e insuficientemente confiables para los reemplazos de articulaciones.
Palabras clave: teoría de confiabilidad, confiabilidad operacional, cargador frontal de un cubo, transmisión, reparación operativa.

1. Introduction

At present, a significant improvement in the technical indicators of machinery and equipment is required to increase their potential. At the same time, machines and equipment, constructively, become more complex and, as a consequence, more and more labor and material costs are required for their production and operation. The costs of maintaining and restoring the operability of construction and road machines are 6-10 times higher than the cost of a new machine [1].

In this regard, increasing the reliability of machines in operation is a task of great practical importance. At the same time, an important factor is the universality of the machines and equipment in terms of functionality. For numerous enterprises, it is important that the machine purchased can not only produce earthmoving, planning and loading and unloading works, but also be suitable for carrying out a wider range of works. The main part of the fleet of modern machines for the construction of industrial facilities, transport facilities, etc. are SBFLs (single-bucket front loader) equipped with HMD (hydro-mechanical drivetrain), which have become widespread due to their inherent advantages [2,3]. The main feature of the SBFLs operation is the fact that in performing a number of works they replace excavators, bulldozers and other machines, because their ability to perform a wide range of work [4–8].

It should be noted that increasing the reliability and improving the operation of the SBFLs is a large reserve that allows to increase their productivity, to exclude downtime during planned and unplanned repairs.

The practice of the SBFLs operation at industrial facilities in East Kazakhstan shows that some machines are often out of service and for a long time, require constant intervention of maintenance personnel in order to replace failed parts and assemblies.

2. Main part

The increase in reliability of SBFL is primarily due to a reduction in the total unit costs for the acquisition of machines and maintenance of their operability in operation. This is achievable when using a system of group substitutions of parts and components that limit its reliability. Within it, one should strive to ensure that each of the parts of the machines can be restored independently of the others.

Implementation of this approach requires the development of methods to increase reliability, primarily, aggregates and assemblies that limit the reliability of the SFBL. Based on the operational tests of SFBL L-34B and 534C, it is revealed that the efficiency of their operation depends to a large extent on the state of HMT, in which the gearbox (GB) 8 is the least reliable unit. GB reasons to 93.98% of HMT failures.

It should be noted that the traditional methods of ensuring the reliability of HMT, based on the system of preventive maintenance, do not provide the full necessary result on the one hand, and on the other - lead to greater material and financial costs of operating enterprises. It is established that the existing methods of ensuring reliability and organization of repairs of HMT OPF do not allow providing the most effective, from the point of view of economics, resource-saving in the field of managing the processes (system) of maintaining efficiency.

Thus, the current situation determines the need for a scientifically grounded approach in order to improve the reliability of machines.

---

3. Methods of study

With the help of methods of reliability theory, it is possible to solve the problems of ensuring the reliability of construction machinery, equipment and mechanisms at different stages of the life cycle of machines and mechanisms. In this case, the general approach to the estimation of reliability of technical objects is based on the interpretation of the failure [10].

In this study, the development of a method for modeling the reliability of machines was made possible by analyzing the results of previously performed work[12–16]. At the same time, the question of choosing the ratio for calculating the costs of maintaining the reliability of machines $C_{rm}(t)$ that are convenient from the point of view of computer simulation was initially worked out. Attention is paid to the coverage of a wide range of parts and machine subassemblies, as well as the reliability of the final results of modeling.

Let some product (subassembly, assembly, machine) consists of various parts, and the failure of any of them leads to the failure of the entire product. If $C_{Dj}(j=1,2,...,M)$ is the cost, and $\omega_j(t)$ – the recovery density of the *j* part, then the total cost of maintaining the reliability of the product per unit of time is determined by the formula

$$C_{rm}(t) = (D+1) \cdot \sum_{j=1}^{M} C_{Dj} \cdot \omega_j(t), \qquad (1)$$

where the coefficient $D = A + B + C$ takes into account the costs associated with the replacement: *A* – coefficient, due to labor costs to replace parts: *B* – a coefficient that takes into account the cost of materials; *C* – a coefficient that takes into account the costs of spare parts and materials; C – is a coefficient that takes into account losses due to machine downtime.

In actual conditions, the service life of the product is limited, and the number of parts replacement is not great. In the considered time interval, a fairly accurate approximation of $C_{rm}(t)$ by a fifth-degree polynomial with respect to *t* is possible, i.e.

$$C_{rm}(t) = \sum_{i=1}^{5} a_i t^i. \qquad (2)$$

Integrating $C_{rm}(t)$ and dividing the result by *t*, we obtain the average specific costs $C_{avg\,rm}(t)$ for maintaining the reliability of the product[17]:

$$C_{avg\,rm}(t) = \sum_{i=1}^{5} \frac{a_i t^i}{i+1}. \qquad (3)$$

The total unit costs, taking into account the initial cost of the product C_P, will be equal

$$C_{pu}(t) = \frac{C_P}{t} + C_{avg\,rm}(t). \qquad (4)$$

With increasing *t*, the first term in (4) decreases, and the second increases. The value of *t* at which $C_{pu}(t)$ assumes the minimum value is usually called optimal resource t_{opt} of the product. In this case, the costs of maintaining reliability for the period of the optimal resource are calculated by the formula

$$C_{rm}(t_{opt}) = \sum_{i=1}^{5} \frac{a_i t_{opt}^{i+1}}{i+1}, \qquad (5)$$

and the level of reliability *n* of the product is estimated by the formula proposed by prof. A.M. Sheinin[16,17]

$$n = \frac{C_P}{C_{rm}(t_{opt})}. \qquad (6)$$

Fot the sake of completeness of the product reliability analysis of the probability of failure-free operation *P(t)* the average operating time of the product is also calculated for the first failure T_0 according to the generally accepted formulas.

Formulas (1) – (6) are basic in analyzing the impact of cost and reliability characteristics of parts on the output parameters of the product. However, for the use, it is necessary to have explicit dependences for calculating $\omega_j(t)$.

Previously, formulas were proposed for calculating $\omega_j(t)$, and then $C_{rm}(t)$ for the case of distribution of parts resources by the normal distribution law. In this case, simple and general recovery processes are considered[18,19].

The above prerequisites and the derivation of formulas for calculating the characteristics of recovery processes, as well as studies aimed at ensuring the accuracy of computer calculations, allow to proceed to the development of methodological principles for modeling and the choice of output parameters for the improved product for both normal resource distribution and distribution of Erlang.

Initial data when performing calculations on a computer are entered in the following sequence: the number of parts in the product – *M*; the number of replacements for each part is *m*; the cost of the product C_u, the coefficients – *A, B, C*; cost of parts – C_{Dj}; average operating time of parts - $t_{avg\ ij}$; mean-square deviations of details – σ_{ij}; number of the improved part – *P*; the maximum operating time is t_{lmt}; the Erlang distribution parameters are $\lambda_1, n_1^{'}, \lambda, n^{'}$.

When modeling the level of reliability of a product, the *j*-th part is replaced with a more perfect one, in other words, it provides an estimate of the output reliability indicators of the product (with the help of a computer) when it "works" with parts of different durability, cost, manufacturing quality, etc.

To compare the characteristics of the improved and the original parts, coefficients were used that indicated a relative change in the corresponding characteristics. If C'_D and C_D, t'_{avg}, t_{avg} – accordingly cost and average resources of the improved and initial detail, i.e.

$$\mu = C'_D/C_D,\ \rho = t'_{avg}/t_{avg}\ ,\ k_n = \mu/\rho \qquad (7)$$

respectively, the coefficient of increase in value, the coefficient of increase in the resource and the coefficient of proportionality. However, they do not cover such important factors as the dispersal of the parts resource, the design and technological features of the products in which they operate, and the conditions for their operation.

In connection with the above, the coefficient k_{rd}, called the coefficient of resource dispersion

$$K_{rd} = V'_D/V_D, \qquad (8)$$

where V'_D and V_D are the coefficient of variation of the improved and original detail, respectively.

Decreasing k_{rd} from the standpoint of reliability is desirable and possible on the basis of taking design and technological measures and improving the operating conditions of the part (product). It is considered to be: k_{rd} the higher the lower the quality of the part. This inverse proportionality created inconvenience. Therefore, the coefficient K_{QC}, named coefficient of quality change

$$K_{qch} = 1/K_{rd}. \qquad (9)$$

In the case of an exponential distribution, $K_{rd} = K_{qch} = 1$. For the case when parts resources are distributed according to the Erlang law, V_D can not be changed arbitrarily, but can only be changed discretely.

As the output parameters of the product, the following results were chosen based on the simulation results: reliability level – *n*; the optimal resource is t_{opt}; costs for maintaining reliability for t_{opt} – $C_{rm}(t_{opt})$; the minimum total average unit costs – $C_{pu\ min}$ and the mean time to the first failure – T_0.

Thus, using the results of the theory of reliability and computer simulation, a method has been developed to improve the reliability of the machine assembly in relation to the TM of the L34B, 534C SBFLs HMD[20].

The criterion determining the optimum values of the reliability index of the TM is the technical and economic criterion. This takes into account the structural and technological factors of the assembly under study[21]. With this approach, it is possible to scientifically justify recommendations for designers and technologists on increasing the durability of insufficiently reliable machine parts.

4. Results of study

In accordance with the developed mathematical model for calculating the reliability indices of technical systems, computer simulations were carried out. At the same time, a computer program was developed that makes it possible to perform the corresponding calculations, including with respect to distributions of the parts operating time under Normal law, Weibull law, and Erlang law. The calculation of the following reliability indicators for the L-34B and 534C front loaders is performed: the operating time to the first failure, the minimum total unit costs for maintaining reliability, the optimum resource and the level of reliability. During the calculation of the costs of maintaining operational reliability, the nature of the operating repair work was taken into account when eliminating the failures of the TM and the regularities of the processes of restoring its operability. Calculation of the leading function of the failure flow is carried out with respect to the processes of restoring the machine's operability, including the general nonstationary process with the help of the developed refined computer modeling program.

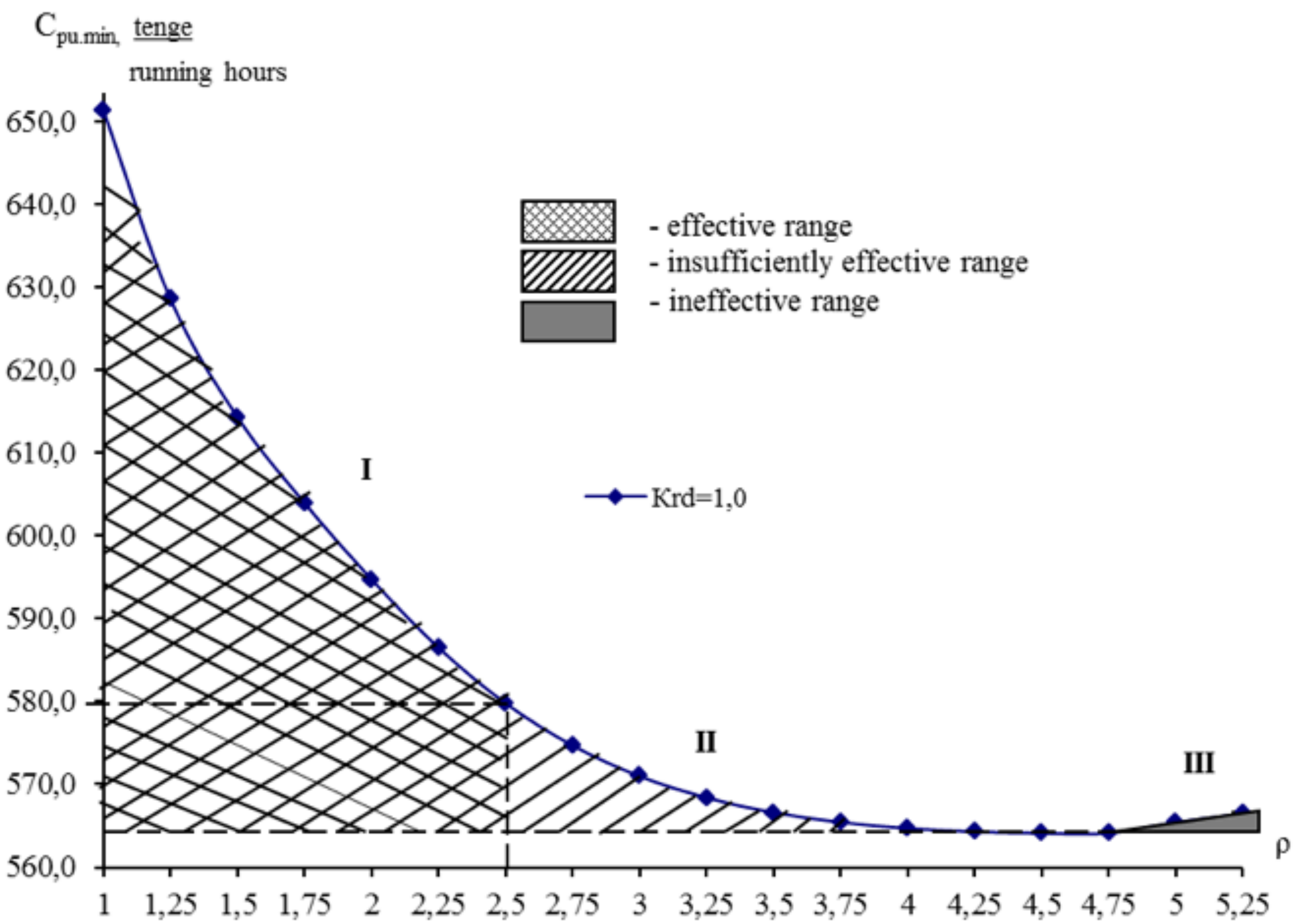
To increase the level of reliability of the machine assembly, it is proposed to reduce the number of operating repairs by improving the reliability of the least reliable, unreliable and insufficiently reliable groups of parts of joint replacements. For this purpose, computer modeling was performed to increase the resource and cost parameters of the most frequently failing groups of parts of the SB 165-2 TM.

Modeling the costs of maintaining operational reliability is based on the nature of the change in failure, i.e. based on the leading function of the failure flow [22]. At the same time, the reliability index of SB 165-2 TM is taken into account as a whole.

Let's consider the results of computer simulation of reliability indicators of the least reliable group of parts of the TM (group of parts No. 3)[8]. As a result of computer simulation, the dependence of the value of the minimum total unit costs $C_{pu\,min}$ on the durability of the least reliable group of TM parts was established. The optimal values of the resource indices of the parts in the composition of each of the local groups are determined to reduce losses from incomplete use of their resources and cost[20].

Analysis of the dynamics $C_{pu\,min}$ from the increase in the resource of parts in ρ times allowed us to distinguish three characteristic ranges of the index change (Fig. 1). The first range is effective (in the range of values ρ to 2.5), where the greatest decrease of $C_{pu\,min}$ is observed in the case of an increase in the resource of the least reliable group of parts of the TM. The second range is insufficiently effective (in the range of values ρ from 2.5 to 4.75), when the decline of $C_{pu\,min}$ slows down until the indicator reaches its lowest value. The boundary between the first and second ranges is determined by the value of α from the largest change in the reliability index (a value of α within 80% is used in reliability theory to establish acceptable values of indicators). The third range is ineffective (in the interval of values of ρ from 4.75 and more), where $C_{pu\,min}$ growth begins.

Fig 1
Dynamics of the minimum total specific costs depending on the resource change of the least reliable parts group of the SB 165-2 transmission

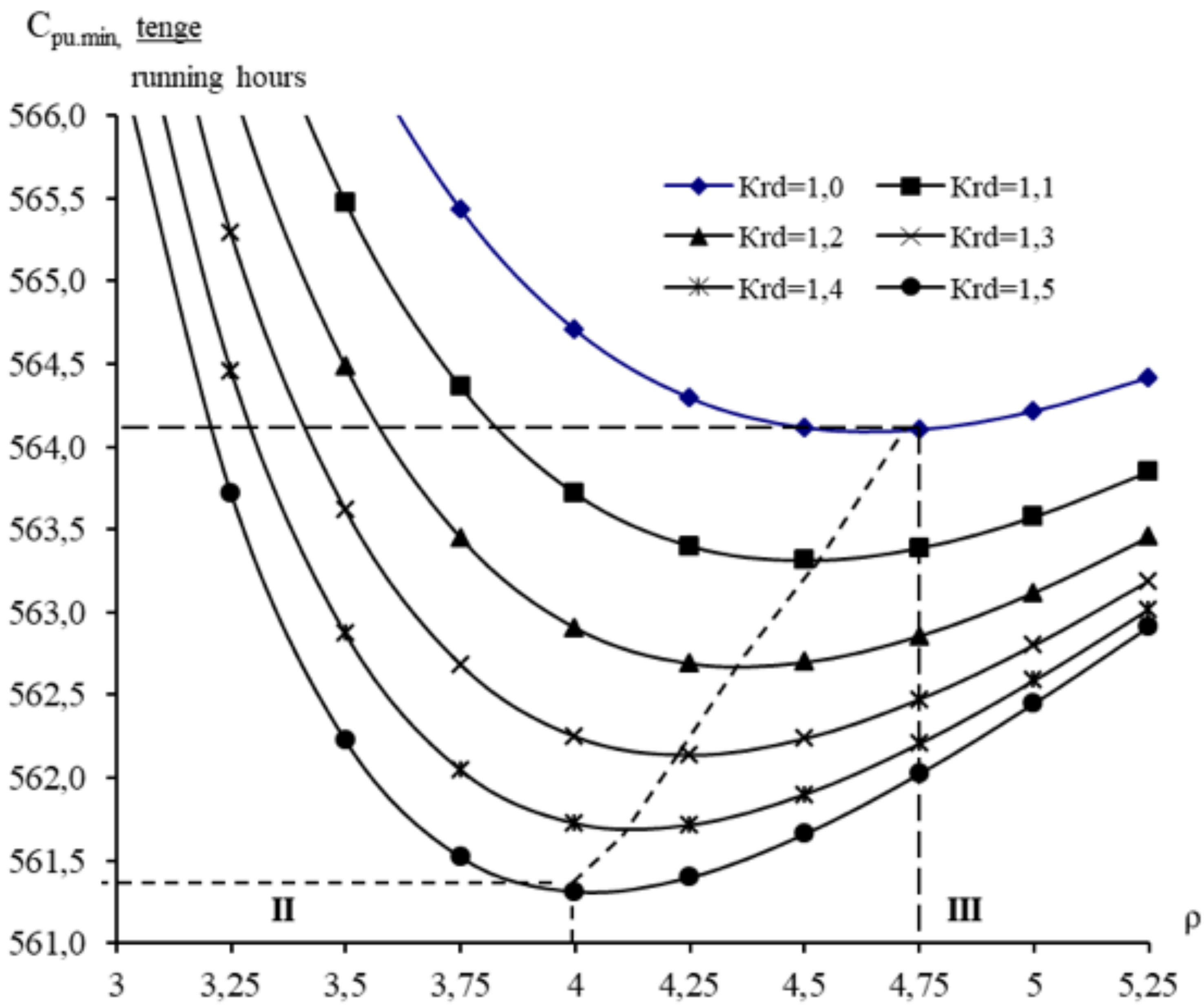


From the point of view of practical importance, the presence of the first and second ranges in the simulation testifies to the possibility of further modernization of the existing design of the TM by simulating the imitation of increasing the durability of groups of joint replacement parts that limit its reliability. In addition, in the case of upgrading (improving the design) of the subassembly under consideration by ensuring the longevity of the least reliable group of parts, it is in the second zone that an acceptable (in terms of economic justification) event should be located.

The mathematical model developed in the course of this work, and the calculation programs allow simulating the effect of improving the manufacturing quality of parts and assemblies on the output reliability indicators of the assembly ($C_{pu\,min}$, n, t_{opt}, T_{bf}). In this case, the coefficient of dissipation of the resource of a part (group of parts) was used to estimate the change in the quality of production. It is accepted that the lower the coefficient of variation (dispersion of the resource) K_{rd}, the higher the quality of the part production (group of parts).

Fig. 2 shows the dynamics of the minimum total unit costs depending on the resource change and the coefficient of dispersion of the resource of the least reliable part group of the SB 165-2 TM. As it can be seen, in the case of improving the manufacturing quality of the least reliable group of parts of the assembly under consideration, the minimum values $C_{pu\,min}$ for computer simulation are reached at smaller values of ρ. In particular, within K_{rd} = 1.5 the minimum value $C_{pu\,min}$ is reached when ρ = 4.0. Modeling on the computer the manufacturing quality of the least reliable group of parts allows us to identify the pattern of the $C_{pu\,min}$ declining (Figure 2).

Fig 2.
Dynamics of the minimum total average specific costs depending on the resource change and dispersion of its least reliable parts group of the SB 165-2 transmission



It has been established that in order to reduce the number of repairs to the SB 165-2, in order to reduce the corresponding costs, it is necessary to ensure equal (multiple) durability of the parts included in the general design and technological group. At the same time, the proposed approaches allow estimating the limits of the increase in the longevity indexes of parts that limit its reliability, with a significant increase in the reliability level of the GB SB 165-2 control unit as a whole and a reduction in the costs of maintaining its operability in operation.

5. Conclusion

As a result of computer simulation of the reliability level of the least reliable group of parts, GB SB 165-2 defines the limit of its improvement. Similar results for the calculation of the minimum total unit costs, the level of reliability of the GB SB-2-2-2 were obtained for the other groups of parts under consideration.

The results of this study made it possible to determine the limits of the optimum increase in the reliability indices of the frequently failing groups of parts of GB SB 165-2. In particular, for the least reliable groups of parts of GB SB 165-2, the durability can be increased in the range 2.0-2.5. It is established that it is possible to reduce the minimum total unit costs for maintaining the reliability of the aggregate under review to 15.1%.

References

1. Kutuzov V.V. Effektivnost' ekspluatatsii stroitel'nykh i dorozhnykh mashin s uchetom izmeneniya ikh tekhnicheskogo sostoyaniya//Tekhnologiya kolesnykh i gusenichnykh mashin. Nauchno-issledovatel'skiy institut konstruktsiy avtomobiley (Moskva). – 2015. – No. 3 (19). – P. 57-64.

2. Griff M.I., Kaganovich Ye.M., Kazimirov L.P., Yagudayev L.M. Pogruzchiki Mira: Spravochnik. – M.:Izd-vo Assotsiatsiya stroitel'nykh vuzov. – 2005. – Vol. 10. – 216 p.

3. Chellini R. New driveline for mini wheel loaders// Diesel Progress International Edition. 2004. – Vol. 23. – Iss. 2. - p. 75 (internet resource https://www.scopus.com/).

4. Dolgikh Ye. S., Makhno D. Ye. Analiz nadezhnosti frontal'nykh pogruzchikov na gornodobyvayushchikh predpriyatiyakh severa// Vestnik irkutskogo gosudarstvennogo tekhnicheskogo universiteta. – 2014. – No. 6 (89). - P.54-59.

5. Roskam R., Dobkowitz D. Modeling of a front-end loader for control design// 2015 23rd mediterranean conference on control and automation (MED). - 2015.– pp. 442-447 (internet resource https://www.scopus.com/).

6. Senthil Kumar, P.S., Srinivasan, P. , Palati, K.K. , Mallela, G. Design, development and evaluation of dual belleville clutch in front end loader tractor for clutch life enhancement//International Journal of Mechanical and Mechatronics Engineering. - 2015. – Vol. 15. - № 1. – pp. 79-88 (internet resource https://www.scopus.com/).

7. Nilsson, T., Fröberg, A., Åslund, J. Predictive control of a diesel electric wheel loader powertrain// Control Engineering Practice. - 2015. –Vol. 41. - pp. 47–56 (internet resource https://www.scopus.com/).

8. Zhandarbekova A.M. Formirovaniye ratsional'nogo kompleksa tekushchego remonta korobki peredach odnokovshovykh frontal'nykh pogruzchikov/ Izvestiya Tomskogo politekhnicheskogo universiteta. – 2014. – Vol. 324. – №2. – P. 52-55.

9. Nadezhnost' mashin i mekhanizmov: Uchebnik/V.A. Cherkasov i [dr], pod red. B.A. Kaytukova i V.I. Skelya; M-vo obrazovaniya i nauki Ros. Federatsii, nats. issledovat. Mosk.gos. stroit. Un-t Moskva: NIU MGSU, 2015. - 272 p.

10. August G., Baratta A., Casciati F. Probabilistic methods in structural engineering. - London: Chapman and Hall. - 1984. - 556 p.

11. Beichelt F. Replacement policy based on the maintenance cost rate// JEEE Trans. Reliab. -1982. - R-31. - pp. 391-393.

12. Franken P., Streller A. Reliability analysis of complex repairable systems by means of marked point processes.// J. Appl. Probab. - 1980. – № 17. - pp. 154-167.

13. Boland P.J., Proschan F. Periodic replacement with increasing costs at failure. FSU Statist. Report № M578 / AFORCE Technical Report. - 1981. - pp. 78-123.

14. Tadikamala P.R. Age replacement policies for Weibull failure times// JEEE Trans. Realiab. - 1980. – V.R-29.- Iss.1. - pp. 88-90.

15. Sheynin A. M. Zakonomernosti vliyaniya nadezhnosti mashin na effektivnost' ikh ekspluatatsii. M.: Znaniye. - 1987. - 54 p.

16. Sheynin A.M., Sheynin V.A. Modeli optimizatsii normativov nadezhnosti mashin i ikh konstruktivnykh elementov // Optimizatsiya protsessov ekspluatatsii stroitel'nykh i

dorozhnykh mashin: Sb. nauch. tr. / MADI-M. – 1983.

17. Kul'seitov ZH.O., Lis’yev V.P. Matematicheskiye modeli i podderzhaniye nadezhnosti mashin. – Almaty: Gylym. – 1996. – 222 p.

18. Kulseitov ZH.O., Lis’yev V.P. Issledovaniya v oblasti protsessov vosstanovleniya rabotosposobnosti mashin//Izv. NAN RK: Ser. Fiz-mat. Nauk. – 1993. –No.3. – P. 71-75.

19. Dzholdasbekov U.A., Kulseitov ZH.O. Vosstanovleniye rabotosposobnosti mashin i mekhanizmov vysokikh klassov// Dokl. MN-AN RK. – 1997. – No.2. – P55-60.

20 Verigin YU.A., Kulseitov ZH.O., Zhandarbekova A.M. K resheniyu voprosa sokrashcheniya ob”yemov tekushchego remonta korobki peredach pogruzchikov modeley L-34B i 534S./ Izvestiye Vysshikh uchebnykh zavedeniy «Stroitel'stvo» Novosibirsk 2012, No. 10 (646) P. 74-80.

21. Parts catalog 534C Serial NUMBERS 20001 And UP DRESSTA Co. LTD. AJOINT VENTURE OF KOMATSU AMERICA INTERNATIONAL CO END HUTA STALOWA WOLA S.A.CATALOG CZESCI PARTS CATALOCUE.

22. Zhandarbekova A.M. Povysheniye urovnya nadezhnosti dorozhno-stroitel'nykh mashin i effektivnost' ikh ekspluatatsii./ Respublikanskiy nauchnyy zhurnal «Nauka i obrazovaniye yuzhnogo Kazakhstana». 2012. – Shymkent, 2012 – No.3/4 P. 164-167.

---

1. Ph.D. of Engineering Science, Senior Lecturer at the S. Seifullin Kazakh Agro-technical University. E mail: AZhandarbekova@bk.ru

2. Ph.D. of Engineering Science, Senior Lecturer at the L.N. Gumilyov Eurasian National University. Email: dauren78@mail.ru

3. Ph.D. of Engineering Science, Associate Professor at the Kazakh Academy of Transport and Communications named after M. Tynyshpayev. E mail: mkaken@mail.ru

Ph.D. of Engineering Science, Senior Lecturer at the S. Seifullin Kazakh Agro-technical University. E mail: erlanktz@gmail.com

---