

ANNOTATION

dissertation work Zhumekenova Zaure Zhetpisbaevna
«Improving the durability of wheel sets of railway cars by restoring the tread surface
with laser cladding», submitted for the degree of Doctor of Philosophy (PhD)
in the specialty 8D07101 – «Mechanical engineering»

The relevance of the work. Due to the geographical features of the Republic of Kazakhstan, within the mainland, in the center of Eurasia, railway rolling stock, track machines and special-purpose complexes are actively used to ensure transport communication and cargo turn over. In the Republic of Kazakhstan, railway facilities form the infrastructure and ensure the import and export of the national economy market. The railway fleet in Kazakhstan for 2021 averages 1,7 thousand locomotives, electric locomotives and diesel locomotives, 291 automated machines and complexes, 2,7 thousand passenger cars, 28 thousand baggage cars, 54,9 thousand freight cars and 75,5 thousand railcars owned by private companies. With this volume, about 65% of the railway fleet is morally and physically worn out, which reduces their efficiency and economic feasibility of using. «The Tulpar-Talgo» LLP plant existing in Nur-Sultan has a narrow specialization in the production of passenger cars, its capacities do not provide Kazakhstan with a full turnover of railway freight fleet funds, which indicates the relevance of the topic of ensuring the durability of railway cars by technological methods.

Currently, large industrial enterprises have railway sidings in their facilities, as well as railway repair units. Operation in different climatic zones and features of the functionality of the rolling stock lead to intensive wear of critical components, parts and, as a result, to a sharp decrease in the resource durability and safety of the train. Dynamically active systems are subject to the most progressive wear and loss of reliability, especially the running gear of railway cars. Due to the high cost of new wheelsets from 1,5 million tenge to 3,5 million tenge, unstable inflation, as an alternative to new ones, it is proposed to restore worn-out wheels of wagons. There is a shortage of enterprises that can ensure the restoration of wagon wheels in Kazakhstan, and they carry out repairs directly on the basis of their own organization. The issue of effective restoration of wheel sets at a distance from repair points along the route has not been fully studied. Existing restoration methods do not meet the requirements for the quality of the modified surface, and the physical and mechanical properties are lower than those of new wheelsets. Thus, the scientific and practical problem of eliminating defects and carrying out major repair and restoration work at a distance from the depo and repair bases has not been solved. The scientific problem is the lack of reasonable methods for ensuring the durability of railway wheels in the field using highly concentrated sources of laser energy and reasonable optimal technological recovery modes.

The leading Kazakh and foreign scientists M.M. Mashnev, S.A. Aizinbud, A.E. Tsikunov, A.F. Bogdanov, D.P. Kononov, A.N. Bludov, Yu. V. Gomonets, I. A. Ivanov, A. A. Vorobyov, S. V. Krotov, R. S. Ustemirov, professor V.G. Albrecht, M.F. Verigo, A.B. Vasiliev, V.A. Grishchenko, L.O. Gracheva, V.N. Danilov, V.M. Ermakov, M.P. Ershkov, Hou K., V.G. Galaburda, E.P. Isaenko, M.P. Pakhomov, I.I.

Galiev, N.I. Karpuschenko, Oztürk, V., Arar, O.F., A.Ya. Kogan, Rende, F. Ş., L.P. Lingaitis, S.I. Klinov, K.S. Kaspakbaev, N.K. Isingarin, T.B. Bayakhmetov, R.K. Satova, M.A. Levinzon, Weber H., A.D. Omarov, I.V. Prokudin, V.O. Pevzner, Yu.S. Romen, S.N. Sharapov, I.I. Chelnokov, Esveld, V.F. Yakovlev, S.V. Vertinsky and many others.

The purpose of the dissertation is to ensure the durability of wheel sets by increasing the resource of the wheels of a railway car by developing a mobile repair complex and laser technology for restoring wheels.

To achieve this purpose, it is necessary to solve the following **tasks**:

- develop a methodology for substantiating the main dynamic factors that affect the wear of the contact surface and the formation of fatigue stresses in the base of the wheel pair metal;
- to investigate the nature and establish the permissible limits of wear of the wheel elements, which determine the choice of a technological method for increasing the resource of restored wheels of a railway train;
- to substantiate the criteria for the effectiveness of restored wheel sets of railway cars;
- to experimentally investigate the effect of deposited material on tensile and compressive stresses in the coating during laser restoration of car wheels;
- to establish the dependences of the change in microhardness, the phase structure of the restored surface on the modes of laser restoration;
- to develop a mobile complex for laser restoration of wheels;
- to develop a technological method and substantiate the optimal modes for restoring the profile of the rolling surface of wheelsets by laser energy sources.

Research methods. The studies were carried out on the basis of the principle of a system-structural approach and an integrated research method, which includes: theoretical analysis based on mechanical engineering technology and experimental and theoretical studies that have been tested in production and laboratory conditions. Theoretical studies were based on the use of methods of the theory of numerical solutions of mathematical problems using simulation modeling of the interaction of a car wheel with a rail. For the reliability of the research results in the modeling, licensed software applications were used: AutoCAD, MatLab, Solidworks, Microsoft Visual Studio.

The object of the research is technological methods for restoring and increasing the resource of worn-out wheels of a railway train.

Subject of research – dependence of the mechanical properties of the coating on the regime parameters of the technological process of laser restoration of worn-out wheels of a railway train.

The scientific novelty of the dissertation work lies in the following provisions and results:

- the dependences of the distribution of the static load on the coefficient of utilization of the carrying capacity of the car are established ($P_{st}=8,430\lambda+65,343$); dependence of the dynamic load on the static load of the car ($R_d=1,0862R_{st}-65,6814$); the dependence of the coefficient of vertical dynamics on the speed of the car ($k_d = 0,0134v + 0,0297$) and the dependence of

the static load on the gross weight of the car ($P_{st} = 0,023m_{br}^2 - 0,770m_{br} - 5,573$), taking into account dynamic factors that form local wear of the contact surface and fatigue stresses in the basis of the wheelset material;

- the mathematical model of wear of the tread surface and the crest is improved, taking into account the action of distributed dynamic forces when driving on straight and curved sections, as well as changes in the friction coefficient affecting slippage and the stability factor against derailment;
- dependencies are established that describe the polynomial law of change in normal stresses $\sigma_N = -1,502F^2 + 29,959F + 371,874$ and bending stresses, respectively, on the wear of the contact surface of the wheel, taking into account the deviation of the contact patch towards the wheel flange;
- the dependence of the thickness of the laser cladding on the power of laser radiation and the speed of laser cladding was established;
- a methodology and algorithm for substantiating the efficiency criteria for retreadable wheel sets of railway cars was developed, which form the criteria for choosing the main parameters and material for laser technology;
- experimentally substantiated the criteria for the quality of the deposited coating with a variation in the modes of laser restoration of car wheels;
- dependences of changes in the physical and mechanical properties of the restored surface on the deposition thickness, defocusing of the laser spot, microhardness and penetration depth have been established, which make it possible to substantiate the optimal technological modes of laser restoration.

Practical significance. The developed mobile repair complex for the restoration of wheel sets of railway cars allows you to quickly restore worn wheels in the field at a distance from the repair depo. Its unique repair booth platform provides the process environment and conditions for a fixed repair station. The manufacturability of the proposed equipment allows you to automate the process and reduce its energy consumption. The introduction of the developed new mobile complex into the infrastructure will solve the technical problem of increasing the overhaul life of the wheels. The developed mobile complex with a laser energy source provides restoration with any complex-component and refractory material. Laser surfacing provides the width of the surfacing seam depending on the nozzle diameter and allows flexible control of the physical and mechanical properties of the coating. The power of the laser pulse provides a point effect, eliminating overheating of the entire part, leading to heating. The use of a laser energy source in a mobile complex will provide effective control of thermodynamic processes during the formation of the surface and structure of the wheel. Investigated optimal technological recovery parameters improve the quality of the coating, eliminating tensile and compressive stresses.

Established dependences of changes in the physical and mechanical properties of the restored surface on the technological modes of laser reduction. These dependencies make it possible to reasonably choose the optimal values of the modes for restoring the worn tread surface and the wheel flange. The variability of reasonable recovery parameters affects the formation of the optimal microhardness of the coating,

high adhesion strength and increases wear resistance, which leads to an increase in the life of the car wheels.

The provisions of the dissertation submitted for defense:

- Reasonable criteria for evaluating the durability ($P_{st}=109,5$ kN, $\lambda \leq 1$, $P_d=32,8$ kN, $kd=1,3 \cdot 10^6$) of wheel sets and dependencies describing the uneven distribution of static and dynamic loads on the coefficient of utilization of the carrying capacity of the car, on the static load of the car, on the coefficient of vertical dynamics, on the speed of the car and the dependence of the static load on the gross weight of the car, taking into account dynamic factors that form local wear and fatigue stresses in the base material of the wheel pair contact surface.
- An improved mathematical model of the wear dynamics of the tread surface and the ridge, when driving on straight and curved sections, taking into account the progressive change in the contact geometry of the wheel with a variable coefficient of friction and the safety factor against derailment in real operating conditions.
- Methodology and algorithm for substantiating efficiency criteria ($\varphi = 66^\circ$, $\sigma_F = 123,347-295,025$ MPa, $\sigma_N=415,5 \cdot 10^6$ Pa) of retreadable wheel sets of railway cars, forming criteria for choosing the optimal values of parameters and material for laser technology.
- Dependences of the modification of physical and mechanical properties and the graininess of the phase structure of the wheel and crest of the railway car on the technological modes of laser reduction.
- Design and technological parameters of an innovative mobile repair complex for laser restoration of the worn surface of the wheels of railway cars, depending on the quality criteria of the restored surface.

Approbation of work.

The main results of the dissertation were reported at the following international and Kazakh scientific and practical conferences and technical seminars: Materials of the VI International Scientific and Practical Conference "Youth and Science - 2019" (Petropavlovsk, 2019); Materials of the international scientific and practical conference "Kozybayev Readings - 2020: priority areas of development, achievements and innovations of modern Kazakhstan science" (Petropavlovsk, 2020), technical meeting at the Remplasma LLP enterprise (Petropavlovsk, 2021). Structural, technological and methodological developments were discussed and approved at production and technical meetings of Petropavlovsk Expert Center LLP (Petropavlovsk, 2020), Vector SK + LLP (Petropavlovsk, 2021), also during the period of scientific foreign training in SibADI, Omsk (RF), 2021.

Publications.

The main results of the dissertation research are presented in 11 scientific and methodological works: 3 scientific articles in scientific journals included in the peer-reviewed list of KOKSON RK; 2 articles in a foreign scientific journal included in the SCOPUS scientific citation database - Q-2, CiteScore Scopus percentile - 57 and 71; 4 scientific articles in collections of international scientific and practical conferences. Received 1 KZ patent for a utility model and published 1 teaching aid.

Author's personal contribution.

The main results of theoretical and experimental studies were obtained by the author independently. In printed works that are written in co-authorship, the applicant has a leading role in the calculation, generalization and analysis of the results obtained.

Dissertation structure.

The dissertation work consists of an introduction, four chapters, a conclusion, a list of references and applications. The work is presented on 132 pages, contains 74 figures, 16 tables and a list of references from 134 titles of publications of domestic and foreign authors.

Research results.

A method has been developed for calculating the strength characteristics of the wheels of railway cars, taking into account the deviation of the contact patch of the worn part of the surface with a cyclic distribution of shock dynamic loads and axial moments. The implemented technique makes it possible to determine the fatigue stress localization zone and predict a defect before it is detected. This approach improves the manufacturability of the structure during its design, the reliability of the dynamic system and increases the overhaul life of the wheelset.

The developed methodology and algorithm for ensuring the durability of railway wheels makes it possible to substantiate the criteria for the effectiveness of wheel sets of railway cars. The substantiated criteria of the proposed algorithm provide a reliable choice of the restoration method, and the cause-and-effect relationships of defects established in it create the possibility of the optimal choice of technological modes of restoration or modification of the worn wheel tread.

A virtual simulation model for studying the process of localization of stresses along the contact elements of the wheel in different intervals of impact loads is proposed in the Solidworks environment.

The developed mobile repair complex for the restoration of wheel sets of railway cars allows you to quickly restore worn wheels in the field at a distance from the repair depo. Its unique repair booth platform provides the process environment and conditions for a fixed repair station. The manufacturability of the proposed equipment allows you to automate the process and reduce its energy consumption.

The introduction of the developed new mobile complex into the infrastructure will solve the technical problem of increasing the overhaul life of the wheels. The developed mobile complex with a laser energy source provides restoration with any complex-component and refractory material. Laser surfacing provides the width of the surfacing seam depending on the nozzle diameter and allows flexible control of the physical and mechanical properties of the coating. The power of the laser pulse provides a point effect, eliminating overheating of the entire part, leading to heating. The operation of the mobile complex provides system control of thermodynamic processes during the formation of the surface and structure of the wheel. Investigated optimal technological recovery parameters improve the quality of the coating, eliminating tensile and compressive stresses.

The developed algorithm and technological method of laser restoration of a worn wheel increases the variability of technological modes of restoration, expands the horizon of opportunities for improving and modifying the physical and mechanical properties of the modified worn wheel surface. The uniqueness of the proposed laser

source is adapted to harsh conditions of restoration at a distance from repair bases and allows achieving a thermally stable surfacing process with a minimum depth of penetration of the base metal in a short period of time. The developed method of restoration increases the list of products to be restored.

Scientific and practical problems have been solved, aimed at improving the reliability, durability and efficiency of shaping the rolling stock wheel pairs and allowing to fundamentally change the concept of repair and restoration work of a railway train without decommissioning the car along the train route.

Works published about the topic of the dissertation:

1. Zhumekenova Z.Zh. Analysis of the most common defects in wheel sets of railway cars // Proceedings of the VI International Student Scientific and Practical Conference "Youth and Science - 2019", NKSU named after. M. Kozybaeva, Petropavlovsk, 2019.

2. Zhumekenova Z.Zh., Bondarev V.K. Types of defects in wheel pairs of railway cars and ways to eliminate them // Scientific journal "Bulletin of KazNITU" Series of technical sciences. - Almaty, 2019. - S. 376-384.

3. Zhumekenova Z.Zh., Savinkin V.V., Kolisnichenko S.N. On the issue of promising technologies for the restoration of wear surfaces // Scientific journal "Bulletin of KazNITU" / KazNITU named after K.I. Satpaev No. 2 (138), Almaty, 2020. - P. 170-177.

4. Zhumekenova Z.Zh., Savinkin V.V., Abilmazhinova A.S., Seitova A.T. Investigation of the reasons of resource longevity decrease of railway cars' wheel pairs // Scientific journal "Bulletin of KazNITU" / KazNITU named after K.I. Satpaev No. 2 (138), Almaty, 2020. - P. 239-245.

5. Zhumekenova Z.Zh., Abilmazhinova A.S., Seitova A.T. Zhylzhymaly qyramga qyzmet korsetu zhane zhondeu zhyesindegi resource ynemdeu tehnologiyalyary // Proceedings of the international scientific-practical conference "Kozybaev Readings - 2020: Priority Directions for Development, Achievements and Innovations of Modern Kazakhstan Science", III Petropavlovsk, 2020. - P. 275-279.

6. Zhumekenova Z.Zh., Abilmazhinova A.S., Seitova A.T. Modern technologies for the restoration of wagon wheels // Proceedings of the VII International Scientific and Practical Conference "SCIENCE AND EDUCATION IN THE MODERN WORLD: CHALLENGES OF THE XXI century", Nur-Sultan, October 20-22, 2020. - P. 233-237.

7. Zhumekenova Z.Zh., Savinkin V.V., Kolisnichenko S.N., Kolisnichenko S.V., Koptyaev D.A. Study of the dynamic model of the crank-slider mechanism of piston pumps of the drilling complex // Proceedings of the international scientific and practical online conference "Youth and Science - 2021" (April 9), No. IV, Petropavlovsk. - pp. 377-379.

8. Savinkin V.V., Zhumekenova Z.Zh., Kolisnichenko S.N., Sandu A.V., Ivanova O.V., Petrica Vizureanu, Savinkin S.V. Study of wear and redistribution dynamic forces of wheel pairs restored by a wear-resistant coating 15CR17NI12V3F / Coatings 2021, 11(12), 1441. <https://doi.org/10.3390/coatings11121441>. CiteScore Scopus Percentile - 57.

9. Savinkin V.V., Kolisnichenko S.N., Sandu A.V., Ivanova O.V., Petrica Vizureanu, Zhumeckenova Z.Zh. Investigation of the strength parameters of drilling pumps during the formation of contact stresses in gears / Applied Sciences (Switzerland), 2021, 11(15), 7076. <https://doi.org/10.3390/app11157076>. CiteScore Scopus Percentile - 71.

10. Seitova A.T., Zhumeckenova Z.Zh. Machine zhasaudagy standardtau zhane sapany baskaru // ISBN Petropavlovsk: IPO SKU im. M. Kozybaeva, 2021. P. 102.

11. Pat. KZ No. 5935. Mobile repair complex for the restoration of wheel sets of railway cars / Savinkin V.V., Shagaev I.V., Zhumeckenova Z.Zh.; publ. 03/19/2021, bul. No. 11. - 4 s.