ANNOTATION

dissertation for the degree of Doctor of Philosophy (PhD) in the field of preparation 8D071 - “Engineering and Practice of Engineering”, in the educational program 8D07101 - “Mechanical Engineering”.

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DEVELOPMENT OF TECHNOLOGY FOR RESTORATION OF MATING SURFACES OF PARTS OF THE TYPE OF BODIES OF ROTATION

Relevance of the dissertation work. The dissertation was completed within the framework of the State Program for Industrial and Innovative Development of the Republic of Kazakhstan for 2015-2019 and 2020-2025, as well as the “Project to Strengthen Industrial Safety in Central Asia”, for the degree of Doctor of Philosophy PhD in the field of preparation 8D071 - “Engineering and Engineering business", according to the educational program 8D07101 - "Mechanical Engineering".

In modern mechanical engineering, a special role is given to repair production due to the fact that today more than 40% of imports in Kazakhstan are mechanical engineering products, which include equipment for the mining and metallurgical complex, agricultural machinery, cars and much more.

The main indicators of the quality of machines, mechanisms, parts and assemblies are laid down at the stages of the product life cycle - these are the stages of design, construction, production, but defects often arise during the operation stage. Most of these parts are made from difficult-to-machine materials, the machinability of which is several times worse than that of conventional structural materials. Therefore, the organization of repairs and management of repair facilities occupies an important place in the production infrastructure of any enterprise, and the development of this industry is an important issue for ensuring the economic basis of the country.

Studying the work of repair enterprises in the Karaganda region, it was found that most often parts such as bodies of rotation of dynamic equipment of complex geometry of foreign production are subject to repair. 60% of parts such as rotating bodies are currently sent for repair and restoration after wear as a result of operation in order to use their residual resource.

When restoring such parts, machine-building and repair enterprises of the Karaganda region spend a large amount of surfacing material due to the complete restoration of the entire part and a large number of cutting tools, since the restored surfaces have high hardness, and therefore it is necessary to develop resource-saving restoration technology that ensures the quality characteristics of the restored parts.

One of the most common connections, which largely determines the life of the chassis and the machine as a whole, are spline connections. During operation, the parts of these connections acquire a large number of various defects: crushing and wear of the working surfaces of the hub and shaft teeth, tooth breakage, jamming, etc.

Currently, there are almost no machines and mechanisms that do not have gear transmission. Of the various types of gears, spline joints are widely used in a number of areas of mechanical engineering, which is explained by their high load capacity, design and technological advantages over other types of shaft-bushing joints. Spline joints are used to fit gears, couplings, disks, flanges, flywheels, chain sprockets, and so on onto the shaft. The reliability and quality of operation of machines and mechanisms largely depend on the operation of spline joints.

Spline joints are distinguished by a wide variety of shapes and sizes; they are stressful and complex parts in structural and technological terms.

During repairs, splined shafts and bushings are usually replaced with new ones after discarding. This leads to a significant increase in the cost of repairs, and if parts are repeatedly replaced during the depreciation period of the machine, their cost may exceed the cost of not only the entire unit, but also the machine. For this reason, the issue of restoring parts with splined surfaces is of particular interest, since the development of restoration technology will reduce the cost of repairing the entire machine.

Today, there is a lot of research in the field of technologies for repairing spline surfaces, however, despite the rich experience and research results, repairing these surfaces using resource-saving technologies remains a strategically important task, especially in the context of Kazakhstan. It is known that the repair and restoration of spline surfaces of parts such as rotating bodies is more economically profitable than the purchase of new parts. Taking into account the fact that Kazakhstan strives to save resources and optimize costs, the issue of researching effective resource-saving repair technologies is relevant.

The hypothesis of the study is the assumption of a possible connection and pattern between the technological parameters of the surfacing and mechanical processing processes with the main quantitative indicators of the quality of the applied and processed layer during restoration.

The purpose of the research is the scientific substantiation and experimental development of technology and tools for the restoration of parts such as bodies of rotation, based on the selection of optimal technological modes, taking into account cost minimization.

To achieve the goal, the following **tasks** were solved:

- the design features of worn surfaces of parts such as bodies of rotation, methods and technologies for their restoration are determined;

- a mathematical model has been developed for calculating technological parameters of surfacing, taking into account the hardness of the deposited layer;

- the wear resistance of deposited surfaces was studied taking into account the technological parameters of surfacing;

- thermal and deformation processes of surfacing and mechanical processing of parts such as bodies of rotation have been studied;

- a resource-saving technology for restoring mating surfaces of parts such as rotating bodies has been developed, taking into account the determination of optimal surfacing and machining modes;

- the developed resource-saving technology for restoring the mating surfaces of parts such as rotating bodies is economically justified.

Research methods. The problems posed in the work were solved by practical and theoretical methods. The theoretical methods that were used in this dissertation include methods for the design and construction of cutting tools, technologies for surfacing worn surfaces, the theory of cutting materials, metal processing technologies, mechanical engineering technologies, methods for determining the physical and mechanical properties of hardfacing.

Experimental studies on surfacing were carried out in the laboratory of the Kazakhstan Institute of Welding of the Karaganda Technical University named after Abylkas Saginov using a semi-automatic device PDG-252 from SELMA.

The hardness of the deposited layer was measured using the equipment of the testing laboratory of the engineering profile of the KarTU named after Abylkas Saginov “Comprehensive development of mineral resources”.

The wear resistance of deposited surfaces was determined in the laboratory of the Department of Mechanical Engineering and Materials Science of Vilnius Gediminas Technical University.

In the process of conducting dissertation research, the following application packages were used: AutoCAD, KOMPAS-3D Viewer, EXCEL, Ansys Workbench 19.2 with the Welding Distortion extension, BETA CAE System, ABAQUS.

The scientific novelty of the study is as follows:

1. A technology has been created for restoring the mating spline surfaces of parts such as bodies of revolution: which includes:

- improvement of the technological process of hardfacing spline surfaces;

- development of the design of a prefabricated disk cutter with replaceable plates for dimensional processing of splines.

2. An equation was obtained for assessing the hardness of the deposited layer depending on the strength of the welding current, welding voltage, and wire feed speed using the semi-automatic hardfacing method.

3. For the first time, the thermal and deformed state of the deposited surfaces was modeled using the ANSYS Workbench 19.2 program and additional WeldingDistortion and MovingHeatSource extensions and it was found that when hardfacing using a semi-automatic method:

- optimal technological modes reduce the thermal effect on the restored surface;

- optimal technological modes ensure minimal deformations.

4. For the first time, the stress-strain state of a new design of a prefabricated disk cutter with replaceable inserts was simulated, taking into account cutting modes and cyclic loading in the BETA CAE System/ ABAQUS program and the performance of this design was justified.

Scientific provisions submitted for defense:

– technology for restoring mating spline surfaces of parts such as rotating bodies;

- results of an experimental study assessing the hardness and wear resistance of the deposited layer;

- equation for assessing the hardness of the deposited surface;

- results of modeling the surfacing process using the Ansys Workbench software package and results of modeling the strength calculation of the tool design using BETA CAE SYSTEM/ ABAQUS;

- technical specifications for the development of a prefabricated cutter for dimensional processing of splines.

The author defends:

1. Design solutions;
2. Mathematical model;
3. Results of experimental studies;
4. The proposed technology for restoring spline surfaces.

The object of the study is the technological processes for restoring worn surfaces of parts such as rotating bodies.

Subject of research: relationships and patterns between technological parameters of hardfacing and mechanical processing modes with the main quantitative indicators of the quality of the applied and processed layer during restoration.

The practical significance of the study is:

- establishing optimal modes for semi-automatic surfacing and milling of deposited surfaces of parts such as bodies of rotation;

- development of a methodology for determining temperature fields during the surfacing process in Ansys Workbench;

- development of a prototype of a prefabricated disk cutter with replaceable inserts for dimensional processing of deposited spline surfaces;

- method of strength calculation of the design of a prefabricated disk cutter with replaceable inserts in BETA CAE System/ ABAQUS;

- development of recommendations for the use of resource-saving technology for restoring spline surfaces of parts such as rotating bodies.

The results of the research were introduced into the production of Hansa-Flex Gidravlik Almaty LLP (Karaganda).

Summary.

In the first chapter, an analysis of the state of the research problem is carried out, the design features of worn surfaces of parts such as bodies of revolution are determined. A review of existing methods for restoring parts such as bodies of revolution by surfacing is made, as well as a review of methods for mechanical processing of deposited spline surfaces.

In the second chapter, the methodology and results of experimental studies of the semi-automatic method and modes of hardfacing mating surfaces of parts such as bodies of rotation. The hardness and wear resistance of the deposited layer were studied, and a mathematical model of the dependence of the hardness of the deposited layer on the technological conditions of surfacing was developed.

In the third chapter, simulation modeling of the surfacing process was carried out with the development of a model, establishment of a task and analysis of heat transfer problems and structural-static problems, followed by analysis of the results. During the modeling, hardfacing modes for spline surfaces of parts such as bodies of revolution were established, which confirm the conclusions obtained during experimental studies, and also that with increasing parameters of current (I = 135 - 260 A), voltage (U = 17.5 - 24 V) in hardfacing modes there is a tendency to increase residual deformations (from 0.23 mm to 0.39 mm).

In the fourth chapter, a special tool design has been developed for machining the deposited surfaces of parts such as rotating bodies. The calculation and design of a prefabricated cutter for dimensional processing of splines was carried out, as well as simulation modeling of the stress state of a prefabricated cutter with replaceable plates during machining.

The performed dynamic analysis showed the degree of tool utilization in percentage terms of 79% (corresponding to a safety margin of ≈ 20%), which is a sufficient condition. The developed design of a prefabricated cutter with replaceable plates satisfies the standard safety factor, which allows its use when processing deposited surfaces.

In the fifth chapter, the economic efficiency of the proposed resource-saving technology for restoring spline surfaces of parts is calculated. The total cost of production was calculated, the profit of the enterprise and the payback period of the product were determined.

Recommendations have been developed for the production of surfacing worn spline shafts, as well as drawings for the manufacture of a special prefabricated cutter for the dimensional processing of splines.

Personal contribution of the dissertation candidate. The work was carried out by the author personally, the author performed a patent analysis of known designs of metal-cutting tools, a review of theoretical research in the field of the theory of welding processes and machine repair, surfacing technology with imparting specified mechanical properties, as well as features of subsequent processing. The problem was set and a research methodology was developed, the

design of a prefabricated disk cutter was designed and modeled, the optimal technological modes of surfacing were determined and experimental studies were carried out to determine the hardness and wear resistance of the deposited layer.

Publication and testing of the work. The main provisions of the dissertation were published in 11 scientific papers in Russian and English, including 2 articles in Scopus journals with a percentile of at least 25 (Journal of Applied Engineering Science (47%), Tehnički vjesnik (41%)), 3 articles in publications recommended by the Committee for Quality Assurance in Education and Science of the Republic of Kazakhstan, 1 article in the RSCI RSCI database. The research results were reported and discussed at international scientific conferences: X International Scientific and Technical Conference (Omsk, April 26–28, 2021), International scientific and practical conference "Integration of science, education and production - the basis for the implementation of the Nation's Plan" (Saginov readings No. 13), (Karaganda, 2021), III All-Russian scientific and technical conference with international participation, (Tula, 2022), International scientific and practical conference "Integration of science, education and production - the basis for the implementation of the Nation's Plan" (Saginov Readings No. 14), (Karaganda, 2022), International scientific and practical conference "Integration of science, education and production – the basis for the implementation of the Nation's Plan" (Saginov Readings No. 15), (Karaganda, 2023). Received 1 patent of the Republic of Kazakhstan for a utility model and 1 certificate of state registration of rights to an object of copyright. All publications present materials and results of theoretical and experimental studies of the processes of restoration of worn surfaces of parts such as bodies of rotation and subsequent mechanical processing of the deposited layer.

Structure and scope of the dissertation. The dissertation is presented on 144 pages of typewritten text, consists of an introduction, 5 sections and a conclusion, includes 75 figures, 36 tables, a list of used sources of 98 titles and 9 appendices.

Research results and main conclusions.

The thesis contains new scientifically substantiated theoretical and experimental results, the totality of which is important for the restoration of mating surfaces of parts such as bodies of revolution.

As a result of the research work, an important scientific and practical problem of an applied nature was solved, which made it possible to draw the following conclusions:

1. As a result of the study, the hypothesis about the possible connection and pattern between the technological parameters of the surfacing and mechanical processing processes with the main quantitative indicators of the quality of the applied and processed layer during restoration was confirmed.

2. The design features of worn surfaces of parts such as rotating bodies, methods and technologies for their restoration are determined.

3. The optimal mode of semi-automatic surfacing has been established: welding current I = 135A, welding voltage U = 17.5V, wire feed speed 2 m/min,

which ensures the required hardness of the deposited layer 40 HRC, which is as close as possible to the hardness of the spline shaft according to technical specifications requirements 42…56 HRC.

4. An empirical regression equation for determining hardness as a function of welding current, voltage and wire feed speed has been obtained: $Y = 752.8998 + 0.4256X_1 - 22.9583X_2 - 5.2646X_3$.

5. It has been established that there is a tendency towards a gradual increase in the temperature of the original part from the surfacing source (from 22 to 1460 ºC) and an ellipsoidal elongation of temperature fields is observed. It has been established that increasing parameters (I = from 135 to 260 A, U = from 17.5 to 24 V) in surfacing modes tends to increase residual deformations (from 0.23 mm to 0.39 mm).

6. A prefabricated milling cutter with replaceable multifaceted plates was designed for dimensional processing of splines to restore the original geometry and dimensions restored by local hardfacing of splined parts such as bodies of rotation, to improve the technological process of repairing parts.

7. During the simulation of the physical cutting process, the operability of the cutter design in the BETA CAE SYSTEM, ABAQUS program was confirmed. The dynamic analysis showed that the developed design of a prefabricated cutter with replaceable plates satisfies the standard safety factor, allowing its use in processing deposited surfaces.

8. A technology has been developed for restoring spline surfaces of parts such as bodies, taking into account the regulation of technological modes of hardfacing and resource-saving during machining.

9. The results of the dissertation were introduced into the production process of HANSA-FLEX Hydraulik Almaty LLP. Calculation of economic efficiency showed that the use of a prefabricated cutter for dimensional processing of splines during restoration will save 1,852,265.5 tenges per year. The cost of a horizontal milling operation with a reduction in one transition will save 107,806.8 tenges, as well as reduce the time spent on the operation by 10,657 minutes. Recommendations have been developed for surfacing worn spline shafts, as well as technical specifications and drawings for the manufacture of a prefabricated cutter for the dimensional processing of splines.

The payback period, during which investments in production will return as a stream of net profit, is 0.12 years.

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