

## ANNOTATION

dissertations for the degree of Doctor of Philosophy (PhD) in the field of study 8D071 - "Engineering and engineering", according to the educational program 8D07101 - "Mechanical Engineering".

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### **IMPROVEMENT OF TECHNOLOGICAL METHODS ENSURING THE QUALITY OF ELECTRIC MOTOR SHAFTS DURING THEIR RECOVERY**

**Relevance of the dissertation work.** The dissertation was completed for the degree of Doctor of Philosophy PhD in the field of study 8D071 - "Engineering and engineering", according to the educational program 8D07101 - "Mechanical Engineering".

In the current context of industrial development in the Republic of Kazakhstan, characterized by a focus on industrial modernization and resource conservation, the issue of restoring the functionality of critical machine components is of strategic importance. In mechanical engineering and the energy sector, electric motors are the primary power units converting electrical energy into mechanical energy. The stable operation of industrial equipment largely depends on the reliability of its key components, among which the shaft occupies a central place.

An electric motor shaft is a critical component that transmits torque and withstands complex cyclic loads, including torsion, bending, and vibration. Electric motor shafts, being the most heavily loaded components of electric drives, determine the overhaul cycle and overall reliability of production lines. Statistical analysis shows that the primary cause of failure of reconditioned shafts is not a lack of material in the wear zone, but a qualitative change in the physical and mechanical properties of the metal in the heat-affected zone and weld deposit.

Operational analysis shows that shafts operate under conditions of increased wear and fatigue damage accumulation, particularly in stress concentrator areas such as keyways, fillets, and bearing seats. In an industrial region like the Karaganda region, the annual volume of shaft repairs at large repair facilities alone averages approximately 200 units. This confirms the widespread nature of the problem and the high demand for effective repair technologies.

Refurbishing shafts with weld surfacing is the most efficient method in terms of resource conservation. Economic analysis shows that the cost of a refurbished shaft is almost 75% lower than that of a new part. However, despite this economic advantage, there is a serious technical challenge: the service life of refurbished shafts is, on average, half that of new parts. This is due to the occurrence of significant residual stresses and structural heterogeneity in the material after weld surfacing.

While extensive research has been conducted on shaft restoration, ensuring the quality of the restored surface and the durability of the restored shafts is of strategic importance. Given Kazakhstan's commitment to resource conservation and the reliability of repair technologies, improving the technological quality assurance methods for electric motor shafts during restoration is a pressing issue.

**Research hypothesis** There is an assumption about the possible connection and regularity between the technological parameters of the surfacing and heat treatment processes with the main indicators of the quality of the applied layer during the restoration of electric motor shafts, the control of which will significantly increase the fatigue life of the restored shafts.

**Objective of the work:** increasing the durability of restored electric motor shafts by improving the methods of technological quality assurance.

To achieve the goal, the following tasks were solved:

1. the state of the problems of ensuring the quality of restored shafts of electric motors and the analysis of existing technologies for their restoration were studied;
2. The hardness, wear resistance and residual stresses of the deposited layer were experimentally studied under various surfacing and heat treatment conditions using various alloying surfacing materials;
3. the durability of the shaft after surfacing and heat treatment was simulated;
4. a device for centering electric motor shafts after surfacing has been developed;
5. The technical and economic efficiency of the proposed technology and the developed device was assessed.

**Research methods.**

The work uses an integrated approach, combining:

1. Using multifactorial experimental designs to determine the effect of process conditions on the hardness of the deposited layer. Vickers hardness measurement and metallographic studies of the microstructure;
2. the use of mathematical modeling to construct regression equations (linear, quadratic, cubic) to describe the properties of the deposited layer and their optimization through the search for extrema of functions;
3. computer modeling of the stress-strain state and calculation of cyclic durability (SN method) in the ANSYS Workbench and nCode DesignLife software packages using the finite element method;
4. design engineering in the development of basing schemes and 3D visualization of devices in the Autodesk Inventor environment.

**The scientific novelty of the work is as follows:**

1. The dependence of the hardness of the deposited layer for specialized surfacing materials (Sv08G2S, 30KhGSA, OK Tubrodur 35 GM) on the wire feed speed was obtained;

2. The dependences of residual stresses under the influence of induction heating on the speed of movement of the inductor and the frequency of the power source were obtained;

3. The stress-strain state of the shaft after surfacing and heat treatment was simulated in the ANSYS program with an assessment of its cyclic durability;

4. A scientific basis has been developed for the automatic centering of parts along the actual geometric axis using a system of self-aligning brackets and roller supports, minimizing alignment errors.

**Scientific provisions submitted for defense:**

1. technology for restoration of electric motor shafts by surfacing;

2. results of an experimental study of the assessment of hardness and wear resistance, homogeneity of the microstructure and the study of residual stresses in the deposited layer;

3. equation for estimating the hardness of the deposited surface;

4. equation for estimating residual stresses in the deposited layer;

5. fatigue life modeling in ANSYS;

6. technical specifications for the development of a universal self-centering device with self-aligning brackets for shaft centering.

**The author defends:**

1. Results of an experimental study of the assessment of hardness, wear resistance of the deposited layer and residual stresses after heat treatment.

2. Equation for estimating the hardness of the deposited surface.

3. Equation for estimating residual surface stresses after surfacing and heat treatment.

4. Results of modeling the durability of a shaft after surfacing and heat treatment using the Ansys software package.

5. Technical specifications for the development of a new design for shaft centering after surfacing.

**Object of study:** processes of surfacing, heat treatment and centering of electric motor shafts.

**Subject of research:** the relationships and patterns between the technological parameters of surfacing and heat treatment with the main quantitative indicators of the quality of the restored layer.

**The practical significance of the work lies in:**

1. a method for engineering calculations of shaft durability in the ANSYS program, which allows for predicting the service life of a part at the design stage of repair technology;

2. development of a device for centering the shaft after surfacing, ensuring the required processing accuracy even in the absence of standard center holes;

3. in establishing optimal surfacing and heat treatment modes for shaft restoration for repair companies, allowing for a 75% reduction in the cost of work while simultaneously improving the quality of the surface layer.

The research results were implemented into production at KAZTECHPRO

LLP (Karaganda).

### **Summary.**

The first chapter analyzes the current state of the research problem and identifies the main defects of electric motor shafts that can be repaired by surfacing. An overview of existing methods for restoring electric motor shafts by surfacing is provided.

The second chapter presents the methodology and results of experimental studies of a semiautomated method and modes for surfacing electric motor shafts. The hardness and wear resistance, as well as the homogeneity of the deposited layer's microstructure, are investigated, as well as the reduced residual stresses in the deposited layer with properly selected heat treatment. A mathematical model is developed to demonstrate the dependence of deposited layer hardness on surfacing conditions (wire feed speed). A mathematical model is also developed to demonstrate the dependence of residual stresses on heat treatment parameters (power source frequency).

The third chapter presents a simulation modeling of the cyclic life of a reconditioned shaft after surfacing and heat treatment. Using ANSYS software, the distribution of residual stresses and strains in the reconditioned part was analyzed. Based on the simulation, the cyclic life of the reconditioned shaft was assessed and optimal conditions were determined that would increase its life by 30%.

In Chapter Four, a universal self-centering fixture for centering reconditioned shafts after surfacing is developed. The fixture's design and 3D visualization were completed in Autodesk Inventor. A mechanism for automatically centering the part along its actual geometric axis, regardless of wear level and deposited layer characteristics, was developed. Calculations of the structural elements and a performance analysis of the developed device were performed. It was found that the fixture's use improves shaft alignment accuracy and reduces the labor intensity of machining operations after reconditioning.

Chapter 5 provides a technical and economic assessment of the developed technology for refurbishing electric motor shafts. Shaft refurbishment costs are calculated, the cost of the refurbished shaft is determined, and a comparison is made with the cost of purchasing a new part. The economic impact and payback period for implementing the developed technological solutions are estimated. Practical recommendations for the application of rational surfacing and induction heat treatment modes are developed, as well as recommendations for the use of a self-centering fixture in repair facilities. The results confirm the effectiveness of the proposed technology for refurbishing electric motor shafts and the feasibility of its implementation in industrial practice.

Recommendations have been developed for the selection of surfacing modes and high-frequency induction heat treatment of restored electric motor shafts, a method for assessing their durability, and the use of a self-centering device to ensure the accuracy of mechanical processing after restoration.

**Personal contribution of the dissertation candidate.**The author personally completed this work, performing a patent analysis of known shaft alignment devices, a review of theoretical research in the fields of welding theory and machine repair, surfacing technology to impart specified mechanical properties, and the specifics of subsequent processing. The task was defined and a research methodology developed, a universal self-centering device for centering electric motor shafts was designed and modeled, optimal surfacing and heat treatment processes were determined, and experimental studies were conducted to determine the hardness and wear resistance, microstructure homogeneity, and reduced residual stresses of the deposited layer.

**Publication and testing of the work.**The main provisions of the dissertation were published in 10 scientific papers in Russian and Kazakh, including: 1 article in a Scopus journal with a percentile of at least 25 (Journal of Applied Engineering Science (43%)), 3 articles in publications recommended by the Committee for Quality Assurance in Education and Science of the Republic of Kazakhstan. The research results were reported and discussed at international scientific conferences: International - Practical Conference "XVI Saginov Readings. Integration of Education, Science and Production", June 13-14, 2024, International - Practical Conference "XVI Saginov Readings. Integration of Education, Science and Production", June 26-27, 2025, International - Practical Conference of the NAO "Kazakh Agrotechnical University named after S. Seifullin" "Development of the mechanical engineering industry and training of highly qualified personnel of the new formation" May 30-31, 2025. Received One patent of the Republic of Kazakhstan for a utility model and two certificates of state registration of copyright. All publications present materials and results of theoretical and experimental studies of electric motor shaft restoration processes.

**Structure and scope of the dissertation.**The dissertation is presented on 168 pages of typewritten text, consists of an introduction, 5 sections and a conclusion, includes 79 figures, 32 tables, a list of references from 90 titles and 7 appendices.

**Research results and main conclusions.**

The dissertation presents new scientifically based theoretical and experimental conclusions that are of key importance for improving the methods of technological quality assurance of electric motor shafts during their restoration.

During the course of this dissertation research, an important scientific and technical problem aimed at increasing the durability of restored electric motor shafts was solved, and the following conclusions were obtained:

1. As a result of the study, the hypothesis about the relationship between the technological factors of restoration of surfacing and heat treatment and the physical and mechanical properties of the surface layer was confirmed, which allows for the targeted formation of the operational characteristics of shafts, increasing their durability;

2. Empirical regression equations for determining the hardness of the deposited layer from the wire feed speed for the materials Sv08G2S, 30KhGSA and OK Tubrodur 35 GM were obtained:

- SV08G2S:  $y = -45.1232x^3 + 400.2165x^2 - 1099.2045x + 1147.4487$ ;
- OK Tubrodur 35GM:  $y = 33.8424x^3 - 311.0147x^2 + 1000.4974x - 707.5193$ ;
- 30XГCA:  $y = -11.4747x^3 + 87.7887x^2 - 152.4326x + 314.0658$ .

3. Optimal surfacing modes have been established to ensure the required hardness values Sv08G2S – 180 – 220 HV; OK Tubrodur 35 GM – 320 – 400 HV; 30XГCA – 280 – 360 HV:

- $V = 2.75$  m/min,  $I = 128$  A,  $U = 20.4$  V (wire SV08G2S);
- $V = 3.0$  m/min,  $I = 9$  A,  $U = 19.5$  V (OK Tubrodur 35GM wire);
- $V = 2.75$  m/min,  $I = 96$  A,  $U = 19.5$  V (30KhGSA wire);

4. It was established that OK Tubrodur 35GM wire is the most effective material among the tested alloyed wires, since it has a finely dispersed needle-like structure and a minimum friction coefficient ( $f = 0.44$ );

5. The influence of induction heating (IH) parameters on the level of residual stresses was revealed. Optimal heat treatment conditions (inductor speed  $V = 5-6$  m/s at a current frequency of  $f = 60$  kHz) were determined to ensure minimal axial deformations and residual stresses;

6. Using the ANSYS and nCode DesignLife software package, a simulation modeling of the stress-strain state of the shaft after surfacing and heat treatment was carried out;

7. It has been proven that the use of high-frequency heat treatment after surfacing reduces maximum equivalent stresses by more than half. Fatigue life increases from 12,238 to 15,777 cycles;

8. A self-centering device has been designed to automatically identify and record the geometric axis of a shaft being repaired. This technical solution eliminates errors associated with locating the centerline of a part after repair operations.

9. The implementation of the proposed surfacing and heat treatment technology provides an annual income of over 15 million tenge with a restoration program of 200 shafts per year. The payback period for the process is 0.34 years;

10. Recommendations have been developed for surfacing and heat treatment of welded shafts of electric motors, as well as technical specifications for the manufacture of a universal self-centering device with self-aligning brackets for shaft centering;

11. The research results have been implemented into the production process of HANSA-FLEX Gydravlik Almaty LLP and Qaztechpro LLP.

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