ABSTRACT

to the dissertation by Kossanova Indira Muratovna on the topic: “Improving the quality of the surface layer of heavily loaded parts by the plasma treatment method”, submitted for the degree of Doctor of Philosophy (PhD) under the educational program 8D07501 – “Standardization and quality management of products.”

Relevance of the research.

Under the conditions of sustainable economic growth and industrial-innovative development of the Republic of Kazakhstan, increasing the efficiency of the agro-industrial complex (AIC), as one of the key sectors of the national economy, is of particular importance. According to strategic documents, including the Concept for the Development of the Agro-Industrial Complex of the Republic of Kazakhstan for 2021–2030 and the Comprehensive Plan for the Development of the Mechanical Engineering Industry for 2024–2028, priority is given to the introduction of highly efficient, resource-saving, and innovative technologies that contribute to increased labor productivity and reduced production costs of agricultural products.

One of the most important directions for improving the efficiency of agricultural production is the enhancement of the operational characteristics of the working bodies of agricultural machinery. Wear of these components leads not only to a decrease in the quality of soil cultivation, but also to increased repair and maintenance costs, machine downtime, and consequently to higher production costs of agricultural raw materials.

The specificity of Kazakhstan, with its large-scale industrial and agricultural activities, as well as the significant development of agricultural transport, emphasizes the necessity of improving the durability and service life of technical components. Improving the quality of the surface layer of parts in accordance with the methods and technologies described in the regulatory documents of the Republic of Kazakhstan is one of the priority research directions in this field.

The agricultural industry of the Republic of Kazakhstan is represented by enterprises equipped with various machinery, including machine-tractor units, sowing, planting and harvesting equipment, irrigation systems, and fertilizer application machinery.

The plowshares and cultivator sweeps are subjected to the highest impact-abrasive loads (400–650 kg per part), wear, and contact fatigue deformation. According to numerous durability tests, from 10 to 40% of plowshares and cultivator sweeps operating in loamy soils are rejected due to bending and fracture before reaching the limiting wear condition [5,6]. As a consequence, further downtime of machinery caused by wear or low reliability leads to crop losses and additional costs associated with restoring operational performance. According to industrial practice and operational observations for medium-density soils (loams and sandy loams), the mean time to failure of unhardened plowshares and cultivator sweeps averages 720 ha per part, while under more abrasive conditions (sandy soils containing stone inclusions) this value may decrease to 640–650 ha. Thus, the components lose their

operational capability after approximately 700 ha of operation, whereas the technologically justified service life should be 1.5–2 times higher. Consequently, there arises a scientific and technical problem of increasing the wear resistance and durability of heavily loaded components while maintaining their operability under variable loading conditions, which requires the application of effective surface hardening methods.

In the context of active technological development and increasing requirements for the reliability and efficiency of technical systems, the issue of improving the quality of the surface layer of heavily loaded components of agricultural machinery working bodies is highly relevant.

In this regard, the use of efficient plasma hardening to improve the surface layer of loaded parts without deforming the internal metal layer, while ensuring the preservation of carbon concentration in the structure, is of particular importance. This method is promising because it allows smooth adjustment of process parameters during hardening and is practical, economical, and highly productive.

The absence of specialized regulatory and technical documentation comprehensively governing the processes of plasma hardening of structural carbon steels is one of the significant reasons for the reduction in wear resistance, durability, and operational life of heavily loaded parts of tillage machines. Under conditions where there are no unified requirements for plasma treatment parameters, heating and cooling regimes, hardened layer depth, and surface zone structure, the probability of process instability and obtaining non-uniform operational characteristics of hardened parts increases. Solving this problem requires the development of an industry standard capable of regulating and ensuring the quality of plasma hardening, particularly for plowshares and cultivator sweeps made of structural carbon steel

In this regard, **the purpose** of this dissertation research is to develop regulatory documentation for plasma hardening processes by determining and substantiating the optimal plasma hardening parameters.

To achieve this objective, the following main tasks were set and solved:

- Analysis of existing hardening methods for heavily loaded components.
- Study of the effect of plasma hardening parameters on the microstructure and phase composition of 65G steel.
- Construction of a regression model to determine the influence of plasma hardening regimes on the mechanical and operational properties of 65G steel components to optimize the technological process.
- Evaluation of operational and physicochemical characteristics of hardened parts, including surface hardness, hardened layer depth, wear resistance, impact strength, and corrosion resistance.
- Study and evaluation of residual stress distribution in the surface layer after plasma hardening.
- Development of regulatory and technical documentation for the plasma hardening technological process for carbon structural steels.
- Evaluation of the expected economic efficiency from the implementation of plasma hardening technology.

Object of research: plowshare and chisel-shaped cultivator blade.

Subject of research: Influence of plasma hardening regimes on the operational, physical, mechanical properties, and structure of the hardened layer of plowshares and cultivator blades.

Scientific Results Under the Dissertation Requirements.

The introduction substantiates the relevance of the research, defines the aim and objectives, discloses the scientific novelty and practical significance of the results, formulates the main statements for defense, and provides information on the testing of results and the author's personal contribution.

The first section presents an analysis of the current state and operational challenges of agricultural machinery working parts. Particular attention is paid to methods of systematic quality management for heavily loaded soil-cultivating machines, considering their sensitivity to wear, operational stresses, and intense abrasive action. Existing approaches and research in plasma hardening are also reviewed.

The second section presents the objects, materials, and methods of research. The choice of structural material for plasma treatment used in agricultural machinery components is justified. The results of metallographic and X-ray diffraction analyses, microhardness tests, and wear tests describing changes in the structure and physical-mechanical properties of 65G steel under thermal treatment are provided.

The third section addresses the justification and selection of optimal plasma processing regimes for heavily loaded soil-tilling components and includes regression analysis. It presents the evaluation of residual stress distribution in the surface layer after plasma hardening and describes the development of a technological instruction and organizational standard.

The fourth section provides the results of the study on the effect of plasma treatment on the properties of 65G steel, the assessment of hardened layer depth and surface hardness, field tests results for plowshares and cultivator blades on wear resistance, as well as evaluations of steel fracture toughness based on impact and static bending tests with material damage analysis.

The fifth section contains the evaluation of the expected technical and economic production efficiency from implementing plasma hardening technology.

Scientific Novelty.

1. Optimal plasma hardening regimes for plowshares and cultivator blades were developed, providing the formation of layers with enhanced wear resistance and improved physical-mechanical characteristics.

2. The influence of main hardening parameters (current strength, arc voltage, torch-to-surface distance, and torch movement speed) on the formation of hardened layers was determined. Based on regression analysis, patterns of inter-factor interaction of variable parameters were established, with surface hardness identified as the most significant response characterizing the hardening process efficiency.

3. The patterns of residual stress formation and distribution in the surface layer of 65G steel after plasma hardening were studied. The formation of a gradient compressive stress field (up to 353–440 MPa) in the near-surface zone was established, contributing to increased crack resistance and service life of plowshares.

4. A technological instruction for plasma hardening of plowshares was developed.

5. An organizational standard STO LLP – 190740006823-01-2026 “Plasma Hardening of Carbon Structural Steel Products” was developed.

Practical Significance

The practical significance of the obtained results lies in the possibility of applying optimized plasma hardening regimes to strengthen heavily loaded parts of soil-cultivating machinery, which increases the service life and wear resistance of working tools in agricultural equipment. The developed technological recommendations can be used by agricultural enterprises, manufacturers of soil-cultivating machinery, as well as service and maintenance centers.

The study has demonstrated the potential for improving wear resistance and durability of heavily loaded agricultural machine parts using plasma treatment. For this purpose, field tests were conducted jointly with LLP “Nur 777 KAS” (North Kazakhstan region, Akkayyn district), confirming the effectiveness of the proposed plasma treatment regimes.

Relation to Other Research Projects

The dissertation was carried out under the state-funded grant project AR26104483 “Research and Development of Gradient Strengthening of Solid-Rolled Railway Wheels by Plasma Hardening”.

Main Provisions Submitted for Defense

− Scientific justification of the influence of plasma hardening on the structure, operational, and physical-mechanical properties of heavily loaded soil-tilling machine components;

− Development of optimal technological regimes for plasma hardening of heavily loaded agricultural machinery parts;

− Technological instruction for plasma strengthening of plowshares;

− Organizational standard for plasma hardening of carbon structural steels;

− Economic and production efficiency of the plasma hardening method in improving the quality and wear resistance of heavily loaded agricultural machinery components.

Approbation of Results

The main results of the dissertation were reported and discussed at the following international scientific-practical conferences:

− XII International Scientific-Practical Conference “Current Problems of Transport and Energy: Innovative Solutions” (Astana, March 14, 2024).

− LXXXIII International Scientific-Practical Conference “Scientific Forum: Technical and Physical-Mathematical Sciences” (Moscow, April 14, 2025 — Certificate received).

− XCV International Scientific-Practical Conference “Technical Sciences: Problems and Solutions” (Moscow, April 22, 2025).

Publications: 3 articles in international journals indexed in Scopus, 3 articles in journals recommended by COXON of the Ministry of Science and Higher Education of the Republic of Kazakhstan, 1 monograph, 3 papers in international

conference proceedings (including 1 abroad), and 1 additional publication. 1 patent for a utility model of the Republic of Kazakhstan was obtained.

Author's Personal Contribution

The author took an active role in problem formulation, discussion, and result analysis. All experimental results presented in the dissertation were obtained either by the author personally or under her direct supervision.

Structure and Volume of the Dissertation

The dissertation consists of 144 typed pages, including 45 figures and 34 tables. It comprises the table of contents, list of symbols and abbreviations, introduction, five chapters, conclusion, and 157 references.