ABSTRACT

Kolisnichenko Sergey Nikolaevich

«Development of structural and technological solutions to reduce dynamic loads and increase the durability of core drilling pumps», submitted for Doctor of Philosophy (PhD) degree specialty 8D07101 (6D071200) – «Mechanical Engineering»

Relevance of dissertation research. Kazakhstan has a huge reserve of hydrocarbons and makes a significant contribution to the development of the global oil and gas industry. Large international companies of the oil and gas sector are involved in the investment project of Kazakhstan. The development of new strategically important fields with the use of integrated core drilling rigs is particularly attractive for the world's leading oil exporters. Their high efficiency, productivity and resource durability should be ensured by intellectual and technological achievements of industrial and technical development of the industry of Kazakhstan.

The demand of National companies for reliable high-performance pumping complexes is quite huge, and the share of wear is constantly increasing. There is also a progressive increase in the dynamics of prices for energy resources, repair, restoration, and their corresponding maintenance. Technical accidents, failures, shutdowns of drilling rigs in several fields like Tengiz, Uzen, etc., show a lack of knowledge and technologies of repair and restoration, the lack of systems and mechanisms for adapting the strength parameters of pumps, as well as quality control of pumping units. To solve this problem, it is necessary to modernize the structural elements of drilling pumps, which will maintain a positive increase in the quality and reliability of drilling complexes.

The problem of dependence on foreign products can only be solved by import substitution due to new design and technological solutions aimed at the resource durability of pumps of drilling complexes.

Harsh operating conditions of drilling rigs and cyclically changing dynamic loads during drilling tighten the requirements for their reliability and safety of operation.

The development of new progressive technologies for drilling wells requires the development of the theory of increasing resource durability, resource-saving structures of components and assemblies of the drilling rig. In order to increase the efficiency and reliability of the structural elements of the drilling rig, the need for modernization of power plants, pumping units, drives and the working body has increased.

During drilling, repairing, and developing wells, an important place is occupied by drilling pumps, which must maintain functionality in harsh conditions and aggressive environments, therefore, **the relevance of the study** is determined by the need to reduce loads, increase the resource and ensure their durability.

Analytical studies and patent search of existing pump designs and gearing gap control systems in gear coupling teeth have shown that existing designs do not provide load and torque redistribution depending on operating modes and resistances. The cyclic action of dynamic forces changes the structure of the pump elements and leads to failures. To improve the efficiency and quality of operation of the drilling pump, a design of a drilling pump with a gear gap control mechanism is proposed, including an autonomous hydraulic drive system with an eccentric mechanism, load distribution over the surface of the shaft neck, which will allow adjusting the gap and the gear engagement depth, ensuring high operational properties of the pump and optimally distributing the stresses of the transmission and eccentric shafts, taking into account wear of the design geometry of the teeth. It is possible to expand the range of repair dimensions of the eccentric drive shaft and eliminate direct thermal effects on the base of the pump shaft by the developed technological method of restoring worn necks of the eccentric pump shaft by installing heat-strengthened lock-type rings.

The purpose of the current work is to increase the efficiency and ensure the resource durability of drilling pumps by introducing a constructive and technological system for controlling the gear engagement gap and eccentric shaft repair technology.

The purpose of the current research is to solve the following **tasks**:

- to explore the prospects and ways to ensure the durability of core drilling pumps;
- to substantiate optimal dynamic parameters of piston pumps considering non-constant load conditions;
- to develop a methodology for determining the durability of loaded structural elements of a piston pump;
- to improve the mathematical model of the wear process of the shaft gear with uneven distribution of torques and displacement of the contact area relative to the axis of symmetry of the teeth of the drilling pump;
- to substantiate the qualitative criteria of welded heat-strengthened rings of the eccentric shaft of the drilling pump;
- to establish the dependences of changes in the optimal values of the surfacing area, weld depth and welding current on the welding speed mode;
- to develop a technological method for restoring the eccentric shaft of the pump, providing resource durability;

- to develop a constructive control system for the size of the engagement gap in the teeth of the coupling gears of the transmission drive in the drilling pump.

The object of research is drilling pumps for core drilling.

The subject of the study is the dependence of the dynamic load distribution process on the structural elements of the drilling pump and the influence of design parameters on its durability.

Research methods. In the process of dissertation research, proven methods of mathematical analysis, mathematical statistics, theoretical mechanics, hydraulics, simulation modeling, algorithmization, development of technical solutions and tests in production conditions, physical evaluation experiments were used.

The scientific novelty lies in the following provisions and results:

- the mathematical model of dynamic processes in the drilling pump interfaces has been improved, taking into account the hydrodynamics of the drilling process, the geometric criterion $\Delta\Pi_V$ and the coefficient of reduction in the strength of the *Kn*, which determine the relationship between the resistances on the working body and the wear of pump parts;

- the criteria of effective operation and optimal dynamic parameters of the drilling pump are substantiated on the basis of studies of the causal relationship of the resource and non-constant load modes of operation;

- a methodology and algorithm for determining the durability of loaded structural elements of a piston pump has been developed, taking into account the uneven distribution of moments of forces along the transmission shaft of the gear during operational wear;

- a mathematical model of the wear process of the shaft gear is improved when the contact area is shifted relative to the axis of symmetry of the drilling pump tooth;

- the dependences of the coefficient taking into account the sensitivity of the asymmetry of the torsion cycle ψ_τ, on the strength limit $\sigma_в$ of the shaft material, respectively, are established, the polynomial dependence λ= - 7,043$(Z_\varepsilon^2)^2$ + 20,61(Z_ε^2) - 13,21 revealing coefficient Z_ε^2, taking into account the influence of the value of ε_α on the load capacity of the gear;

- the qualitative criteria of welded heat-strengthened rings of the eccentric shaft of the drilling pump are substantiated;

- the dependences of the change in the surfacing area, (S mm^2) and the depth of the weld, mm on the technological modes of plasma welding, as well as the welding speed mode (V *m/h*) are established from welding current, (IA);

- the dependences of the area of the deposited metal on the type of butt welded joint of the semi-rings of the eccentric shaft and the thickness of the base metal are established FCK = 0,02s^2 + 0,12s -0,28.

Practical significance.

The developed method for determining the durability criterion of pumps based on the dependence of the deviations of the engagement contact spot on the action of a dynamically distributed load. The implementation of this technique will ensure effective prediction of failures, and more accurately determine the period of major repairs. The coefficient of deviation of the contact spot introduced in this technique characterizes the magnitude of fatigue stresses, which increases the reliability of the design of the critical elements of the pump.

A causal relationship has been established between the wear intensity *I* of the pump and the zenith angle α of the cutter inlet, $F_{mp}^{D} = f \cdot R_D \cdot ctg(\alpha + \mu)$, this relationship is described by $i \rightarrow \min$, the function of shape change during wear $P_i(x)$. These dependences provide a reasonable choice of optimal parameters of the effective power of the drive unit *N*, kW. depending on the influence of wear and resistance forces of the drive shaft-gear.

Reasonable parameters of plasma welding of half-rings (diameter of the corresponding electrode *d*, mm; welding current I, A; welding speed *V* m/ h; penetration depth, mm; area of the corresponding surfacing S, mm^2), establish dependencies between technological modes and qualitative criteria of plasma surfacing, which increases the technological level of repair of critical parts of the drilling pump drive, form high durability values.

The developed technological method for restoring the shaft necks of pumps with the installation of steel heat-strengthened additional repair half-rings (ARR), provides high wear resistance and fatigue strength of the structural elements of the drilling pump. The method of restoration by installing heat-strengthened rings increases the resource durability and the inter-repair period of highly loaded pump units of the drilling rig by 7% with an optimal ratio between costs and productivity.

The developed design system of the drilling pump drive with an eccentric gear gap adjustment mechanism ensures optimal adjustment of the gear engagement gap of transmission and eccentric shafts and the tooth engagement depth, ensuring long-term preservation of optimal parameters in different loading modes, increasing the efficiency and resource durability of the drilling pump. The developed adjustment design will reduce the wear rate of gear teeth and expand the range of shaft spacing, as well as reduce dynamic loads on the transmission shaft of the drilling pump.

The calculated scheme of the tolerance fields of the original wedge (key) in the plane of fit allows for smooth movement of the adjustment elements without jamming. The use of fixed cracker tolerance fields allows original parts to be manufactured in the conditions of production of drilling rig pumps.

The developed hydraulic drive scheme of the eccentric mechanism regulating the gearing gap eliminates the human factor and provides offline clearance control by changing the moments of forces and pressure in the gear engagement planes.

Relation to government programs.

The work was carried out as a part of grant research program of the Ministry of Education and Science of the Republic of Kazakhstan on the topic of ИРН AP08856129 "Development and implementation of a new energy-efficient technology for laser-plasma manufacturing of a high-performance deep-pumping complex for hydrocarbon production at low-capacity oil and gas wells with a regenerative drive". The research results presented in the study are aimed at solving the problems of industrial engineering development described in the State Program of Industrial and Innovative Development of the Republic of Kazakhstan for 2015-2019 [1], the Ministry of Investment and Development of the Republic of Kazakhstan, and are consistent with the strategic development goals of the State Program of Industrial and Innovative Development of the Republic of Kazakhstan for 2020-2025 aimed at achieving competitiveness of the machine-building industry of the Republic of Kazakhstan in the domestic and foreign markets in solving problems related to increasing technological capacities by stimulating the development of basic production facilities and the implementation of strategic projects.

The statements submitted for defense:

- methodology and algorithm for determining the durability of loaded structural elements of a piston pump, taking into account the uneven distribution of moments of forces along the transmission shaft gear when the contact area is shifted relative to the axis of symmetry of the gear tooth of the drilling pump drive;
- an improved mathematical model of the wearing process of the shaft gear, considering the localization of contact stresses with uneven distribution of dynamic load θ and durability coefficient at a certain surface strength;
- justified criteria for the effective operation of the drilling pump and dependencies regulating the maximum permissible values of technical and operational indicators, taking into account the specific productivity under non-constant load conditions;
- methodology of substantiation of qualitative criteria of welded heat-strengthened rings of the eccentric shaft of the drilling pump with the established dependences of optimization of welding modes of plasma surfacing;
- effective design and technological parameters of additional repair parts and a technological method for restoring the eccentric shaft of the drilling pump with the introduction of steel heat-strengthened rings;
- the developed innovative design system of the drilling pump drive with a fundamentally new eccentric gear clearance control mechanism.

Approbation of the work. The main results of the dissertation research were reported and discussed at the ISPC "Kozybayev Readings: Eurasian potential and new development opportunities in the context of global challenges", Petropavlovsk.

(16.11. 2018), ISPC "Youth and Science - 2019", M. Kozybayev NKU, Petropavlovsk. (12.04.2019), Universiti Malaysia Perlis, The 5th International Conference on Green Design and Manufacture 2019, IConGDM 2019 - Bandung, Indonesia 29-30 April 2019, 2129, 020022, MNPK "Kozybaev readings", M. Kozybaev NKU, Petropavlovsk, (20.11. 2020), Scientific internship at the "Siberian State Automobile and Road University" (SibADI), "Institute of Additional Education" in the direction of "Mathematical modeling and decision theory" (Omsk, 02-08. 06. 2019), as well as in the direction of "Operation of lifting equipment machines and mechanisms in a manufacturing enterprise" (Omsk, 25.02.-11.03. 2021), technical meeting of engineering and technical workers of LLP "Plant of multidisciplinary Equipment" (ZMO) (Petropavlovsk - 09/16/2021), St. Petersburg International Innovation Forum (St. Petersburg St. Petersburg 10-12.11.2021), STC "Materials and Technologies" Peter the Great Polytechnic University (St. Petersburg 13.11.2021).

Publications. The main research results were reflected in 12 scientific papers, including 2 articles published in international peer-reviewed scientific journals available in the Scopus database (Scopus), the CiteScore percentile index (Sitescore) is at least 71 and 58. In the scientific publications recommended by the Committee for Quality Assurance in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan - 2 articles. The results are also reflected in the 7th proceedings of international conferences, including the 1st foreign indexed in the Scopus database (Scopus). The main research results are reflected in one published patent No. 6364 KZ for a utility model.

Personal contribution of the author. The main theoretical and experimental results obtained during the dissertation research were obtained by the author independently. In published scientific papers as part of a team of co-authors, the applicant plays a leading role in the generalization and analysis of the results obtained.

Research results.

During the implementation of the dissertation research, results were obtained that contribute to increasing the resource and ensuring the durability of core drilling pumps, due to the development of structural and technological solutions to reduce dynamic loads. The resource durability of the transmission shaft-gear drive, as the main drive power unit of the drilling pump, is achieved through the development of a system for regulating the gear engagement gap of the transmission shaft, which provides a redistribution of loads and moments depending on operating modes and resistances. A technological method is proposed for restoring worn necks of the eccentric shaft of the pump by installing heat-strengthened lock-type rings, which makes it possible to expand the range of repair dimensions of the shaft and eliminates direct thermal effects on the base of the pump shaft.

A methodology has been developed for assessing the causal relationship between the operating modes of the drilling rig, the resistance forces on the working body and the wear of the elements of the drilling pump.

Dependences are obtained that establish a relationship between the parameters and operating modes of the drilling pump and fatigue stresses in the worn gear of the transmission shaft; an improved mathematical model of dynamic processes of the drive part of the piston pump allows considering torsional oscillations, uneven torques and angular velocities affecting stress concentrations in the piston pump.

The established dependences of the qualitative parameters of the pump transmission shaft recovery technology on the technological modes made it possible to control and minimize fatigue stresses and defects.

The application of the obtained research results in the design of pumps of drilling rigs will increase their service life and will ensure high durability and efficiency of the power machine and drilling complex in all operating modes.

Works published on the topic of the dissertation.

1. Kolisnichenko S.N., Kolisnichenko S.V, Kozhanov V.S. Problemy v povyshenii effektivnosti ekspluatatsii i dolgovechnosti raboty burovykh porshnevykh nasosov [Problems in improving the operational efficiency and durability of drilling piston pumps] //Materials from internationalМатериалы международной scientific and practical conference «Kozybayev readings-2018: Evraziyskiy potentsial i novyye vozmozhnosti razvitiya v usloviyakh globalnykh vyzovov [Eurasian potential and new development opportunities in the context of global challenges]» T2.-Petropavlovsk: M. Kozybayev NKU, 2018. p. 276-277

2. Kolisnichenko S.N., Savinkin V.V., Tomashets A.K. K voprosu vosstanovleniya slozhnykh defektov bazovykh detaley voyennoy Bronetekhniki [On the issue of restoration of complex defects of basic parts of military Armored vehicles] //Materials from ISPC «Kozybayev readings-2018: Evraziyskiy potentsial i novyye vozmozhnosti razvitiya v usloviyakh globalnykh vyzovov [Eurasian potential and new development opportunities in the context of global challenges]» T2.-Petropavlovsk: M. Kozybayev NKU, 2018. p. 328-331

3. Kolisnichenko S.N., Zhakupov M.A., Savinkin V.V. Perspektivnyye sposoby vosstanovleniya khodovoy chasti voyennoy gusenichnoy Tekhniki [Promising ways to restore the chassis of military tracked vehicles]//Materials from ISPC «Kozybayev readings-2018: Evraziyskiy potentsial i novyye vozmozhnosti razvitiya v usloviyakh globalnykh vyzovov [Eurasian potential and new development opportunities in the context of global challenges]», T2.- Petropavlovsk: M. Kozybayev NKU, 2018. p. 227-229

4. Kolisnichenko S.V., Sofin A.A. Analiz energoeffektivnosti i perspektiv sovremennykh konstruktsiy burovykh nasosov dlya ustanovok kolonkovogo bureniya [Analysis of energy efficiency and prospects of modern designs of drilling

pumps for core drilling installations]//ISPC «Youth and science – 2019», M. Kozybayev NKU, 2018. -p. 61-65

5. Savinkin V. V., Ratushnaya T. Yu., Ivanischev A. A. ,. Surleva A. R, Ivanova O. V., Kolisnichenko S. N. «Study on the Optimal Phase Structure of Recovered Steam Turbine Blades Using Different Technological Spray Modes for Deposition of Al2O3»//Universiti Malaysia Perlis, The 5th International Conference on Green Design and Manufacture 2019, IConGDM 2019 – Bandung, Indonesia 2019.

6. Kolisnichenko S.N., Savinkin V.V., Kolisnichenko S.V. Issledovanie dinamicheskih parametrov dvuh i trekhporshnevyh nasosov burovogo kompleksa [Investigation of dynamic parameters of two and three-piston pumps of the drilling complex]// Materials from ISPC «Kozybayev readings», .- Petropavlovsk: M. Kozybayev NKU, 2020, p.291-295.

7. Zhumekenova Z.Zh., Savinkin V.V., Kolisnichenko S.N., K voprosu perspektivnyh tekhnologij vosstanovleniya poverhnostej iznashivaniya [On the issue of promising technologies for the restoration of wear surfaces]// Vestnik KazNITU, №2- Almaty, 2020, p.170-177

8. Kolisnichenko S.N., Savinkin V.V., Kolisnichenko S.V, Kiselev L.A., Kuznetsova V.N. Povyshenie resursa nasosa burovoj ustanovki putem vosstanovleniya geometricheskih parametrov sheek valov temouprochnennymi kol'cami [Increasing the resource of the drilling rig pump by restoring the geometric parameters of the shaft necks with temouprochnennymi rings]// Vestnik KazNITU, №4- Almaty, 2020, p.530-534

9. Savinkin V.V., Kolisnichenko S.N., Kolisnichenko S.V., Koptyaev D.A., Zhumekenova Z.Zh. Issledovanie dinamicheskoj modeli krivoshipno-polzunnogo mekhanizma porshnevyh nasosov burovogo kompleksa [Investigation of the dynamic model of the crank-slide mechanism of piston pumps of the drilling complex]// ISPC «Youth and science – 2021», T4- Petropavlovsk, 2021,p.377-380

10. Savinkin V. V., Kolisnichenko S. N.,Sandu A. V., Ivanova O. V., Vizureanu P., Zhumekenova Z. Z.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

11. Savinkin V. V., Zhumekenova Z. Zh., Sandu A. V., Vizureanu P., Kolisnichenko S. N., Savinkin S. V., Ivanova O.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

12. Patent № 6364 RK on useful model. Burovoj nasos s ekscentrikovym mekhanizmom regulirovaniya zazora shesteren [Drilling pump with eccentric gear clearance adjustment mechanism]/ Kolisnichenko S.N., Savinkin V.V.; Published 27.08.2021, Bulletin №34-5c.