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ABSTRACT

for the dissertation entitled

"Improving the quality indicators of gear pumps with biaxial connection of hydraulic systems of agricultural machines"

submitted in fulfillment of the requirements for the degree of Doctor of Philosophy (PhD) under the Educational program 8D07105 – "Mechanical engineering", field of study 8D071 – "Engineering and engineering affairs", Group of educational programs D103 – "Mechanics and metalworking"

Relevance of the Research Topic. The strategic priorities and development programs of the agro-industrial complex of the Republic of Kazakhstan, particularly the New National Project for the Development of the Agro-Industrial Complex (2024-2028) and the Concept for the Development of the Agro-Industrial Complex for 2021-2030, emphasize the crucial role of agricultural machinery engineering in increasing agricultural gross output and achieving sustainable socio-economic development.

Agricultural machinery operates under severe and unfavorable conditions characterized by a wide range of climatic factors, high levels of airborne dust, the presence of abrasive particles in soil, substantial dynamic loads caused by variable and unstable soil resistance, and random loading conditions. The impact of these factors results in accelerated wear of hydraulic components, assemblies, and units of agricultural machinery, increased rates of failures and breakdowns, and higher fuel consumption. Under such demanding operating conditions, improving the performance and efficiency of agricultural machinery can only be achieved through the advancement of the design and manufacturing technologies of hydraulic devices, assemblies, and units. In this regard, a new design of a gear pump with a biaxial connection (GP-BAC) was developed.

To improve the performance characteristics of the GP-BAC, it was proposed to partially restrict the relative movement of individual components, particularly the support bushings. For this purpose, expanding elements were installed between the support bushings to force them into direct contact with the cylindrical surface of the pump housing bore. However, during operation of the GP-BAC, several drawbacks were identified, including reduced pump capacity and efficiency caused by the unstable performance of the expanding elements.

Initially, springs were used as the expanding elements. The installation of springs between the support bushings requires highly accurate machining of corresponding holes. Manufacturing support bushings with such holes presents significant technological challenges associated with ensuring coaxiality and maintaining precise center-to-center distances between holes located in different bushings.

Therefore, scientific research aimed at improving the performance characteristics of GP-BAC through the enhancement of expanding element and support bushing designs represents a relevant and important engineering task.

The objective of the dissertation is to improve the quality performance indicators of a gear pump with a biaxial connection (GP-BAC) by enhancing the design of the expanding elements and support bushings.

The object of the research is the operating process of a gear pump with a biaxial connection used in the hydraulic systems of agricultural machinery.

The subject of the research is the regularities of the influence of the design, material, and stress-strain state of the expanding elements and support bushings on the quality performance indicators of the gear pump, including operating pressure, internal leakage, volumetric efficiency, temperature conditions, and service life.

The research was carried out using methods of structural analysis of gear pumps (GP) and gear pumps with a biaxial connection (GP-BAC), experimental research, as well as mathematical and computer modeling of the operating process of the GP-BAC with expanding elements made of elastic rubber and steel materials, and support bushings made of polymer material.

Задачи исследования:

1. To analyze the design and investigate the operating process of gear pumps, in particular the gear pump with a biaxial connection (GP-BAC).
2. To select rubber and steel materials with elastic properties for manufacturing the expanding elements of the GP-BAC, and to investigate the feasibility and application of producing support bushings by additive manufacturing technologies.
3. To develop the design of the expanding elements and support bushings.
4. To conduct experimental studies of the operating process of the GP-BAC with various expanding elements made of elastic rubber and steel materials, as well as with support bushings made of polymer material.
5. To perform computer modeling of the operating process of the GP-BAC with various expanding elements made of elastic rubber and steel materials, as well as with support bushings made of polymer material.
6. To calculate the technical, operational, and economic efficiency of the proposed GP-BAC design and to develop recommendations for production.

Scientific Novelty of the Research:

1. For the first time, the quality performance indicators of a GP-BAC were experimentally investigated using expanding elements made of elastic rubber and steel materials, as well as support bushings made of polymer material. It was established that:

- when expanding elements made of elastic rubber and steel materials are used, the generated operating pressure corresponds to the operating pressure of a standard gear pump and prevents the working clearances from opening, which, unlike in standard pumps, makes it possible to maintain high efficiency under increased loads;

- expanding elements made of 65G steel withstand loads of up to 24 MPa, while the radial clearance remains within the range of 0.05-0.15 mm;
- for a bushing made of PLA plastic, the safe load range is up to 12 MPa, while the operating pressure is 1.5-2.0 times lower than that of a standard GP-50U3 pump.

2. Mathematical models have been proposed to describe how expanding elements made of elastic rubber and steel materials press the support bushings against the end faces of the gears under discharge pressure, thereby minimizing leakage.

3. For the first time, the operating process of a GP-BAC with various expanding elements made of elastic rubber and steel materials, as well as with support bushings made of polymer material, was modeled using the ANSYS Workbench and SolidWorks software packages. It was established that:

- the elastic expanding element made of 65G steel retains its profile and mechanical properties during deformation;
- as the load increases, the risk of material damage also increases; at 12 MPa, the stress values are already at the allowable limit for PLA plastics.

Statements Submitted for Defense:

1. The results of experimental studies of the quality performance indicators of the GP-BAC using expanding elements made of elastic rubber and steel materials, as well as support bushings made of polymer material.

2. Mathematical models describing the operating process of expanding elements made of elastic rubber and steel materials, as well as support bushings made of polymer material.

3. The results of modeling the operating process of the GP-BAC with various expanding elements made of elastic rubber and steel materials, as well as with support bushings made of polymer material, using the ANSYS Workbench and SolidWorks software packages.

The validity and reliability of the scientific provisions, conclusions, and results are confirmed by the correct formulation of the research problem and the adequacy of the theoretical and experimental studies.

Patents of the Republic of Kazakhstan have been obtained for the design of the GP-BAC (No. 6789 and No. 11069), as well as for a device for testing gear pumps based on a lathe (No. 6642). A certificate of state registration of rights of the Republic of Kazakhstan for an intellectual property object has also been obtained for the methodology for calculating the stress-strain state of an FDM-printed PLA gear pump bushing by the finite element method in the ANSYS Workbench software environment.

The practical significance of the dissertation consists in the development of:

- the design of the GP-BAC with various expanding elements made of elastic rubber and steel materials, as well as support bushings made of polymer material;

- a methodology for calculating the stress-strain state of an FDM-printed PLA gear pump bushing by the finite element method in the ANSYS Workbench software environment;
- practical recommendations for the implementation and application of the developed design in production.

The author's personal contribution consists in formulating the research objectives and developing the research methodology; designing and manufacturing special configurations of the GP-BAC with various expanding elements made of elastic rubber and steel materials, as well as support bushings made of polymer material; organizing and conducting experimental studies of the operating process of the GP-BAC with various expanding elements made of elastic rubber and steel materials and support bushings made of polymer material; and performing computer modeling of the operating process of the GP-BAC with these design variants.

The dissertation is aimed at fulfilling the main objectives of the development program of the agro-industrial complex of the Republic of Kazakhstan, in particular the New National Project for the Development of the Agro-Industrial Complex (2024-2028), as well as the Concept for the Development of the Agro-Industrial Complex for 2021-2030.

The dissertation was carried out within the framework of the grant projects AP23489364 "Application of Additive Technologies in the Repair of Agricultural Machinery with Process Optimization through Modeling and Experimental Research" (2024-2026) and AP09562459 "Development of a Prototype Gear Pump for Agricultural Machinery Based on a Biaxial Connection" (2021), funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan.

The main results of the dissertation have been recommended for implementation in the production activities of Keruen Tech Trade LLP (Astana, 2025).

Approbation of the Research. The main provisions of the doctoral dissertation were presented and discussed at the meetings of the Department of Technological Machines and Equipment of S. Seifullin Kazakh Agrotechnical Research University (2021-2026), as well as at international conferences:

• International Scientific and Theoretical Conference "Seifullin Readings-18: Youth and Science – A Step Towards the Future" (Astana, 2022);

• International Scientific and Practical Conference "Seifullin Readings-18(2): Science of the 21st Century – The Era of Transformation" (Astana, 2022).

Publications. Based on the results of the doctoral dissertation, 14 scientific papers have been published in Russian, Kazakh, and English, including 4 articles in international scientific journals indexed in the Web of Science or Scopus databases, 1 monograph, and 3 articles in journals recommended by the Committee for Quality Assurance in Science and Higher Education of the Republic of Kazakhstan. The

main research results were presented and discussed at 2 international conferences. In addition, 3 patents of the Republic of Kazakhstan for utility models and 1 certificate of state registration of rights to a copyrighted work were obtained.

Scope and Structure of the Dissertation. The doctoral dissertation consists of an introduction, 5 chapters, and a conclusion. The dissertation is presented on 119 typed pages and includes 78 figures, 17 tables, a list of references containing 87 sources, and 4 appendices.

CONCLUSION

In the course of the dissertation research, a comprehensive study was carried out to improve the quality performance indicators of the GP-BAC by developing the design of expanding elements and support bushings.

The following results were achieved:

1. Designs were developed and experimental prototypes of expanding elements made of elastic rubber and steel materials were manufactured, along with support bushings made of polymer material.

2. It was experimentally established that:

- when expanding elements made of elastic rubber and steel materials are used, the generated operating pressure corresponds to the operating pressure of a standard gear pump and prevents the working clearances from opening, which, unlike in standard pumps, makes it possible to maintain high efficiency under increased loads;
- expanding elements made of 65G steel withstand loads of up to 24 MPa, while the radial clearance remains within the range of 0.05-0.15 mm;
- for a bushing made of PLA plastic, the safe load range is up to 12 MPa, while the operating pressure is 1.5-2.0 times lower than that of a standard GP-50U3 pump.

3. Mathematical models have been proposed to describe how expanding elements made of elastic rubber and steel materials press the support bushings against the end faces of the gears under discharge pressure, thereby minimizing leakage.

4. Modeling using ANSYS Workbench and SolidWorks software packages established that:

- the elastic expanding element made of 65G steel retains its profile and mechanical properties during deformation;
- as the load increases, the risk of material damage also increases; at 12 MPa, the stress values are already at the allowable limit for PLA plastics.

5. Recommendations for production were developed. The technical and economic results obtained using expanding elements made of 65G steel showed that operating pressure increases by 42.9%, volumetric efficiency increases by 8-12%, and service life between repairs increases by 1.5-1.8 times.

The results of the research are recommended for implementation in the production activities of Keruen Tech Trade LLP (Astana).