Ibraim Alibek Samatuly

PhD student Department of Mechanical Engineering of the Kazakh National Research Technical University named after K. I. Satpayev on the topic "Possibilities of using additive technology to improve the design of an BLDC electric motors" for the degree of Doctor of Philosophy (PhD) in the educational program 8D07113 – "Additive manufacturing” the dissertation

Annotation

General characteristics of the work

The dissertation is devoted to the development and experimental verification of the application of additive technologies in the design of brushless direct current (BLDC) electric motors aimed at improving energy efficiency, power density and thermal stability when operating under load. The study is focused on overcoming the limitations of traditional technologies for the production of electrical machines. An analytical review of current research and patent solutions in the field of BLDC electric motors was carried out, which showed that traditional technologies limit the optimization of geometry and the integration of efficient cooling systems, which leads to an increase in heat loss and a decrease in efficiency under variable loads. The methodological basis of the study is a systematic approach to the design of BLDC electric motors, including the author's method for assessing energy efficiency and power reduction under load. The methods of CAD/CAE modeling, FEA, CFD and topological optimization are used in the work. Parametric models of the stator, rotor, and motor housing were developed, taking into account the limitations of 3D printing, and comprehensive thermal and electromechanical optimization was performed. Topological optimization of housings and thermal interface elements with integrated cooling channels made it possible to reduce operating temperatures and increase power output without changing the rotor and power electronics. Experimental tests of the prototypes confirmed the reliability of the calculated results and the practical applicability of the developed solutions, which forms the scientific and engineering basis for the introduction of additive technologies in the new generation BLDC electric motors.

Relevance of the work

The relevance of the dissertation is due to the growing requirements for energy efficiency, specific power, weight and size and thermal reliability of brushless DC motors (BLDC), widely used in electric vehicles, unmanned aerial vehicles and robotic systems. Modern operating conditions are characterized by long-term operation under variable loads and high heat fluxes with strict restrictions on weight and dimensions, which places increased demands on the design of electric motors. Traditional electric machine technologies have limited design flexibility and do not allow for efficient integration of cooling systems, resulting in increased heat loss and reduced energy

efficiency when operating under load. The development of additive manufacturing opens up new opportunities for topological optimization of structures and improvement of heat transfer, but its implementation is constrained by the lack of integrated design methods. In this regard, the development of methods for designing BLDC electric motors using additive technologies and focusing on efficiency indicators is an urgent scientific and technical task.

As a result of the dissertation research, the results of

As a result of the dissertation research, a set of scientific and practical results was obtained aimed at improving the energy efficiency, thermal stability and operational reliability of brushless DC motors (BLDC) developed using additive manufacturing technologies.

An analytical review of current research and patent solutions in the field of BLDC electric motors was carried out, which showed that traditional production technologies limit the ability to optimize geometry and integrate efficient cooling systems, which leads to an increase in heat losses and a decrease in energy efficiency when operating under load. On this basis, requirements for additively-oriented design of electric motors taking into account thermal, mechanical and electromagnetic factors have been formed.

The choice of materials and technologies of additive manufacturing for the manufacture of structural elements of electric motors is substantiated. It has been established that cermet materials based on Al_2O_3 provide higher thermal stability and effective passive heat dissipation compared to traditional aluminum alloys under the same operating conditions.

Parametric CAD/CAE models of the BLDC stator, rotor and motor housing have been developed and complex numerical simulation of thermal, mechanical and electromagnetic processes using FEA and CFD methods has been performed. Topological optimization of the hull and thermally conductive components with built-in internal cooling channels was carried out, which made it possible to reduce the weight of the structure and thermal resistance. The internal volume of the stator cooling channels has been increased from 26 to 132 ml, providing a fivefold increase in the circulating flow of the cooling medium.

A method for quantifying the energy efficiency of BLDC electric motors under load has been developed and tested, taking into account the thermal state of the windings and changes in electrical parameters. It has been experimentally proven that the optimization of the stator cooling system provides an increase in power output by up to 15% without changing the rotor, the use of cermet materials reduces operating temperatures by up to 24%, and the optimized AlSi10Mg alloy housing with integrated cooling channels allows you to reduce the temperature by up to 30% and increase the output power by up to 17%.

The reliability of the results is confirmed by a comparison of calculated and experimental data, and their practical applicability is proven by the implementation of the developed solutions in experimental electric motors for energy-efficient transport and racing plants, which forms the scientific and engineering basis for the development of a new generation of BLDC electric motors.

Purpose and objectives of the study

The purpose of the dissertation is the development and scientific substantiation of approaches to the use of additive technologies in the development of the design of DC electric motors without a collector, which provide an increase in efficiency and a decrease in energy consumption under loads

Objectives of the dissertation

1. Analytical review of current research and patent solutions in the field of additive manufacturing of BLDC motor components with the identification of geometric, thermal and technological limitations of traditional designs and the formation of requirements for additive-oriented design.
2. Substantiation of the choice of materials and technologies of additive manufacturing for the manufacture of stator, rotor and motor housing based on a comparative assessment of polymer, aluminum and metal-ceramic materials in terms of thermal conductivity, heat resistance, strength and manufacturability.
3. Develop parametric CAD/CAE models of BLDC stator, rotor, and motor housing, taking into account the limitations of 3D printing, and perform comprehensive numerical simulations of thermal, mechanical, and electromagnetic processes.
4. Implementation of topological and structural optimization of the hull and thermally conductive components to reduce mass and thermal resistance with the introduction of built-in cooling channels.
5. Development and experimental verification of a methodology for assessing energy efficiency and predicting the decrease in the power of BLDC electric motors under load with an analysis of the technological and economic feasibility of additive manufacturing.

Object of research

Commutatorless DC motors (BLDCs) designed with complementary manufacturing technologies.

Subject of research

Design, heat and power characteristics of DC electric motors without a collector, which determine their efficiency, power and resistance to loads when using additive manufacturing technologies.

Scientific discovery

A method for calculating the efficiency of brushless DC motors has been developed, which makes it possible to quantify the power decrease and increase in power consumption when operating under load, taking into account the thermal state and electrical parameters of the windings. It has been established that increasing the efficiency of the stator cooling system due to topological optimization and the formation of internal cooling channels provides an increase in the output power of the electric motor up to 15% without changing the rotor and other structural elements. It has been experimentally confirmed that the use of metal-ceramic materials based on

Al_2O_3 made by additive manufacturing provides more efficient passive heat generation compared to aluminum alloys, reducing operating temperatures by up to 24%. For the first time, thermal and structural optimization of the AlSi10Mg alloy housing with integrated cooling channels has reduced the operating temperature by up to 30% and increased power output by up to 17% compared to the basic design.

Theoretical significance of the work

A method for calculating the energy efficiency of DC electric motors without a collector has been developed, which makes it possible to quantify the efficiency of an electric motor and power reduction under load, taking into account thermal and electrical parameters.

Theoretical dependencies of the geometry of cooling systems and topological optimization of structural elements on thermal conditions and the effect of direct current on the permissible power density of electric motors without a collector are obtained.

Heat transfer patterns in additively manufactured BLDC motor components made of aluminum and cermet materials determine their thermal stability and energy efficiency during passive cooling.

Practical significance of the results of the work

The developed methodology for calculating the efficiency and power reduction of commutatorless DC motors can be used in the design and modernization of BLDC electric motors to assess their energy efficiency at the digital design stage.

Topologically optimized designs of stators and motor housings, made by additional production methods, make it possible to increase the output power of electric motors by up to 17% without changing the rotor and power electronics only by replacing the structural elements of the cooling system.

The results obtained from the use of al_2o-based metal-ceramic materials produced by 3D printing can be used in the development of passively cooled electric motors that provide more efficient heat dissipation compared to standard aluminum alloys.

Designed and optimized motor housings made of AlSi10Mg alloy with internal cooling channels can be incorporated into the design and manufacturing practices of electric motors for electric vehicles, drones, and energy-efficient electric drives.

Methods and methods of research

The methodological basis of the study is a systematic approach to the design of DC motors without a collector using additive technologies, including the developed methodology for calculating energy efficiency and power reduction when operating under load. The work uses analytical methods of the theory of electrical machines, numerical modeling methods (FEA, CFD), topological optimization, parametric CAD modeling and comparative analysis of materials used for the additive manufacturing of electric motor components.

Scientific provisions submitted for defense

1. The method of calculating the energy efficiency of DC electric motors without a collector, taking into account the thermal state of the windings and the design features

of the motor, makes it possible to quantitatively determine the efficiency and predict a decrease in power when the electric motor is operating under load.

2. Using topological optimization (Generative design) and the additive manufacturing method of internal cooling channels, the internal volume of the stator and standard stator increased from 26 milliliters to 132 milliliters, and the internal circulating water flow increased by 5 times.

3. The use of 3D printed al_2o_3 ceramic materials provides more efficient passive heat generation compared with standard aluminum alloys, and the working temperature of the electric motor can be reduced by up to 24% under the same operating conditions.

4. Thermal and structural optimization of the ALSI10MG alloy motor housing with internal cooling channels made by downstream production results in a reduction in operating temperature of up to 30% and an increase in the power output of the electric motor up to 17% compared with the traditional design.

Degree of reliability and testing of results

Reliability of scientific results

The reliability of scientific results is ensured by the use of substantiated theoretical provisions of the theory of electrical machines, the use of numerical simulation methods (FEA, CFD) and topological optimization, as well as the comparison of the designed data with the results of experimental studies and tests of prototypes of electric motors.

Approbation of the results of work and publications

The results obtained during the dissertation research were presented at the Shell Eco-Marathon Asia, Pacific and Middle East 2024 high-energy vehicle engineering competition, which was held from July 2 to July 6, 2024 in Indonesia (Lombok Island). As part of the competition, an electric motor manufactured by additive manufacturing using FDM (Fused Deposition Modeling) technology was demonstrated.

Based on the results of the dissertation research, two scientific articles were published in journals indexed in the Scopus and Web of Science databases, as well as four articles in scientific journals included in the list of publications recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan. In addition, one patent for an invention was registered based on the materials of the dissertation, confirming the scientific and practical significance of the results obtained; Two more patents have been examined.

Practical implementation and implementation of work results

The results of the dissertation were implemented in the design and manufacture of additively manufactured components of DC electric motors without manifolds and included in experimental samples of electric motors used in energy-efficient prototypes prepared for participation in the Shell Eco-marathon races, as well as in racing cars of the Formula Student student engineering series, where weight is reduced, thermal conditions are improved and energy efficiency is increased efficiency. station.

Structure and Scope of the Thesis

The dissertation consists of an introduction, four chapters and a conclusion. The thesis consists of 128 pages, 40 figures, 13 tables, 76 bibliographic sources.