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STUDY OF ENERGY EFFICIENCY AND THERMAL STATE OF ASYNCHRONOUS MOTORS, USING THE METHOD OF INCREASING ENERGY EFFICIENCY BY REDUCING MECHANICAL LOSSES.

Abstract. This research examines the problem of design and development of the 3-phase induction motors with basic energy efficiency levels(IE1, IE2) with squirrel cage. It addresses those engineers who are involved in the process of improving the design and development of energy-efficient motors. Also, researchers are interested in finding the relationship between temperature state and energy efficiency. The article touches on global energy conservation issues and saving strategies. The originality of the text lies in the study of thermal and electrical fields of the design of commercially produced motors, and the study of the influence of mechanical losses on the temperature state and efficiency level of motors. The proposed work aims to finding the some interconnections between the temperature state and energy efficiency, which, in turn, may have a positive impact on the global energy –saving problems and their solution Reduction of mechanical losses in bearing units for motors is an effective means to increase efficiency. At realization of the given recommendations in designs of energy-efficient motors, further reduction of mechanical losses in motors of general industrial series is possible at the expense of modernization of ventilation units. The test results confirm the correctness of the chosen direction of research and design, which indicates the need to deepen research and expand the experiments. The work continues in the direction of improving active and passive motor cooling schemes.
Keywords. Induction motors, asynchronous motors, energy-efficiency motors, thermal state, temperature state, heating state, cooling optimization, thermal state energy-efficiency motors, cooling energy-efficiency motors.

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ДОСЛІДЖЕННЯ ЕНЕРГОЕФЕКТИВНОСТІ ТА ТЕПЛОВОГО СТАНУ АСИНХРОННИХ ДВИГУНІВ З ВИКОРИСТАННЯМ МЕТОДУ ПІДВИЩЕННЯ ЕНЕРГОЕФЕКТИВНОСТІ ЗА РАХУНОК ЗМЕНШЕННЯ МЕХАНІЧНИХ ВТРАТ

Анотація. Дане дослідження присвячене проблемі проектування та розробки 3-фазних асинхронних двигунів з короткозамкненим ротором з базовими рівнями енергоефективності (IE1, IE2). Текст може бути корисним для інженерів, які займаються проєктуванням і розробкою енергоефективних двигунів та поліпшенням їхньої конструкції. Також дослідникам, які цікавляться взаємозв'язками між температурним станом і енергоефективністю. У статті порушено глобальні проблеми енергозбереження та стратегії економії. Оригінальність тексту полягає в дослідженні теплових і електричних полів конструкції серійно випущених двигунів, і вивченні впливу механічних втрат на температурний стан і рівень ККД двигунів. Пропонована робота спрямована на пошук деяких взаємозв'язків між температурним станом та енергоефективністю, що, у свою чергу, може позитивно вплинути на глобальні проблеми енергозбереження та їх вирішення. Зменшення механічних втрат у підшипникових вузлах двигунів є ефективним засобом. для підвищення ефективності. При реалізації наведених рекомендацій у конструкціях енергоефективних двигунів подальше зниження механічних втрат у двигунах загальнопромислових серій можливе за рахунок модернізації вентиляційних установок. Результати тестування підтверджують правильність обраного напряму дослідження та дизайну, що свідчить про необхідність поглиблення досліджень та розширення експериментів. Продовжується робота в напрямку вдосконалення активних і пасивних схем охолодження двигуна.

Ключові слова. Асинхронні двигуни, асинхронні енергоефективні двигуни, тепловий стан, температурний стан, стан нагріву, оптимізація охолодження, енергоефективні двигуни з тепловим станом, енергоефективні двигуни з охолодженням.

Introduction. This study aims to examine the area of designs of three-phase induction motors with squirrel cage rotors. The study sheds light on the problem of creating constructions of motors with an enhanced balance of energy efficiency and temperature state. This particularly influences changing the frictional losses in the way of increasing the efficiency of the motors. New approaches and relevance are needed to address the problem of creating constructions of motors with an optimal balance of energy efficiency and temperature state.Various approaches to the design of energy-efficient motors are possible, with the complex reduction of all types of losses in the motor. The article analyses the influence of reducing mechanical losses in bearings and cooling fans to increase the energy efficiency of the motor. The paper deals with the electrical engineering problems of designing three-phase squirrelcage induction motors of classes IE1 and IE2, with the prospect of extending the results to motors with higher levels of energy efficiency.

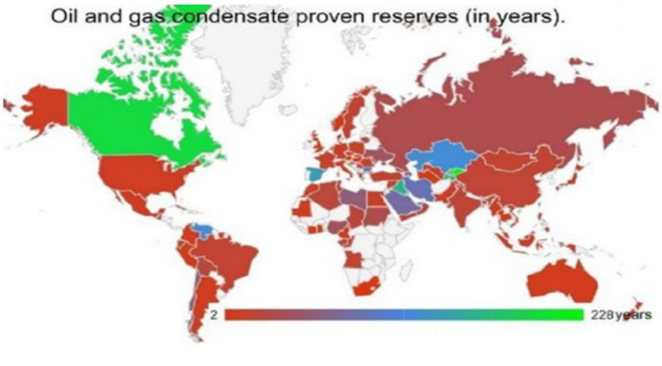

Fig. 1. Oil and gas proven reserves.

It should also be noted that low fficiency levels are considered because of their prevalence in the country. However, the study remains relevant for high energy efficiency IE3, IE4 levels as well.

Topicality. The issues is as follows: from 50 to 65% of all the generated electricity in the world is consumed by electric motors. Up to 70% of the electric motor fleet are squirrel cage induction motors. The largest quantity of operating motors are used in industry. Applied in fan systems or pumping stations, these motors operatealmost 24 hours a day and 7 days a week. Increasing energy efficiency and thus reducing energy consumption is directly related to the topic of global energy savings.Increasing energy efficiency and thus reducing energy consumption is directly related to the topic of global energy savings. We should underline that during the last 50 years, the world has faced several energy crises, which made the world community more attentive to the problems of energy in general, and the energy efficiency of devices - consumers of electricity. Currently, estimates of recoverable oil and gas condensate reserves can last for 30-40 years under an optimistic scenario of their consumption. Thus, today's challenges are the annually growing volume of energy consumed per capita in the world and the high percentage of fossil energy sources (79.68%), the quick pace of exhaustion of the world's proven reserves of fossil energy sources.

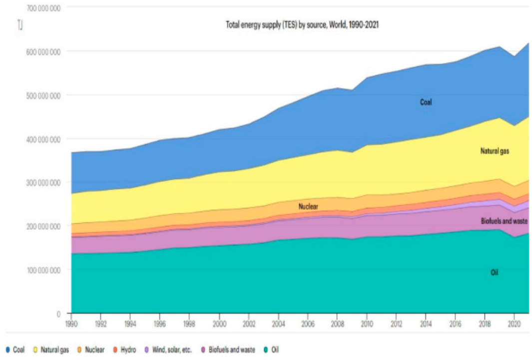

Fig. 2. Total energy supply by source in the word.

As a result, all create a solid background for a global energy crisis in the foreseeable future. As a way out of this situation, the world is actively developing renewable energy-generating sources. The problem is the share of renewable energy resources in the overall volume of generated electricity and heat today is still small, and the cost of renewable energy is several times higher than that of conventional energy. The biggest challenge is that alternative energy projects arecostly and their payback is not quick enough. The accompanying financial crisis challenges the ability to mobilize all the energy investments needed to meet growing energy needs.

Thus, improving energy efficiency and reducing energy consumption is directly related to the topic of global energy savings. It should also be noted that all of the above circumstances limit the implementation of the strategy of transition to renewable energy and increase the risk of a global energy crisis. In these circumstances, saving energy on a global scale is a top priority. One of the stages of its implementation is to save energy from traditional sources by improving the energy efficiency of consumer devices. Development and introduction of energy- efficient motors can be implemented in a relatively short period, and the investments required to arrange the production are much less than the investments required to build new generating renewable energy sources. Needless to say, designing these energy-saving motors with enhanced temperature states is one of the first and vital steps toward the global energy transition from fossil fuels to renewable resources.

To fulfill some further steps, several declarations, technical regulations, and standards have been adopted at an international and regional levels in recent years, regulating mandatory minimum levels of energy efficiency of consumer-devices.

Current situation in this area in the world. Enhancing the energy- efficiency of the squirrel cage induction motors is still in its developmental stages. This trend was significantly intensified with the adoption and implementation of technical regulations of the EU and China, standards of the International Electrotechnical Commission IEC 60034-30 and 60034-31. Referring to the findings from selected scientific databases we infer that this area is still the field of active research in the world, mainly in China, the USA, India, EU. At the same time, the overwhelming number of research are focused on achieving the target level of energy efficiency, without considering the tasks of optimizing the thermal state of the electric machine, and also using the mostly active cooling of the motors. The overall research in this field has a great impact on the global economics and it might be assumed as a

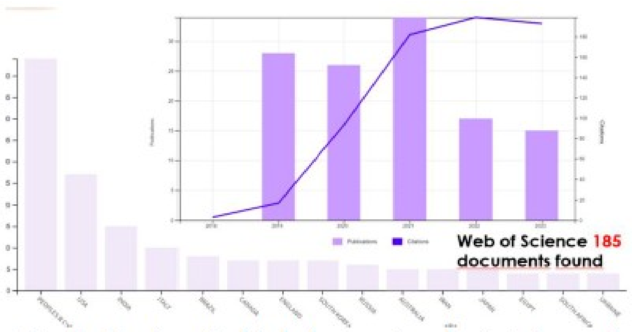

Fig. 3. Number of related documents and cite index on the Web of Science platform

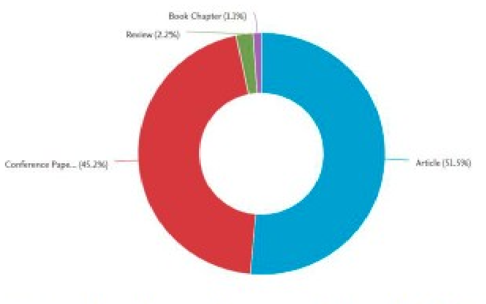

Fig. 4. Distribution of sources of the related documents on the Web of Science platform

huge benefit for the world community, since the major part of the cost of operating motors (up to 96%) is the cost of electricity and only 3% is the cost of purchasing the motor and maintenance. The estimated savings from the implementation of motors with enregy-efficency level are IE3 IEC about 135kWh, compared to the case when no measures are applied. This is equivalent to the level of electricity generation in a European country such as Sweden. It is consistent with the level of electricity generation in a European country such as Sweden. Another positive impact of the research addresses end-users since the major part of the cost of operating motors refers to the electricity consumption of the motors. Moreover, enhancing the temperature state of the motors leads to a lesser probability of faults throughout the motor life-cycle. eview analysis of related sources to determine the current state of the-art. A search for publications relevant to the research topic from international scientific databases was conducted, which yielded the following results. Scopus = 272 documents / Index6.58; Web of Science = 185 documents / Index 3.52; Dimensions = 297 documents /Index 4.22; Search results from scientific databases coincide by 63-92%. The search yielded statistics on publications and citations, and identified the most popular conferences on the topic among the authors of the reports.

There is a strong and modern trend in global science to study ways to improve energy efficiency, which remains relevant.There is also a long-standing and traditional trend in world science to study the thermal state of machines of special design, with special properties or operating modes. The superposition of these trends showed that the proposed research topic is relevant in the world, but has not been studied sufficiently.

The novelty of the topic is to study the thermal state to establish the relationship between the thermal state and increased energy- efficiency of motors by frictional losses. There are typically, exploited designs of electric motors with higher efficiency in contrast with the вinding of power to size according to GOST standards.

As a fact, high prices on the market and substantial differences in technology production interfere with a wider production, operation, and application of these motors. The use of some series of these motors was reduced to a minimum. As a rule, these motors were designed based on existing technological tools, molds, and equipment used in series, only aimed at achieving the target level of energy efficiency and without solving the problems of optimizing the temperature state of the motors and mostly using the proportionally increasing weight of active material of the electromagnetic core. This approach gives stable and good results with efficiency increasing, but as a witness of this is big weight, frame limits, and thermal state of the motor. Solving the tasks require detailed analysis of existing designs of energy-efficient motors and technical solutions, cooling schemes of motors, careful study and comparison of their thermal state, and identification of the influence of structural elements and their changes, to optimize the efficiency and thermal state of the motors. Also, the task is to analyze and study existing motor designs as a first step with basic IE1,IE2 efficiency level and cooling designs with the IC411 code.

Research methods. The methods of the work focuses on the performing modeling and experimental validation of the following directions:

-modeling and examining the electromagnetic and thermal fields for motors of different poles with different energy efficiency classes;

-investigation the effect of the motor's frictional losses in bearings, and the cooling flow rate on the energy efficiency and thermal state of the machine.

The methodology of the research involves the direct method of measuring temperatures with sensors and thermal camera. Temperature condition studies are carried out by means of embedding sensors into the highest heating points of the machine. These sensors are included in the frontal parts of the stator winding, the outer ring of bearings, and the inside in the terminal box. The temperature distribution on the surface of the housing details is measured with a thermal camera. The temperature of the incoming and outgoing air, and air inside of channels (in the case of the motor with a double cooling circulation system) are also measured. The tests of motors efficiency and performance align with IEC 60034-30, IEC 60034-2-1.

The research is carried out in several directions changing the design of the parts of the shell and electromagnetic core. These study directions are as follows :

-a motor with a single cycle of cooling air circulation;

-a motor with different bearings and greases,

-a motor with changed cooling air flow(It is planned to consider further),

The balance of frictional losses spent on active ventilation and the impact on these losses on the motor’s energy efficiency is investigated. The practical results of the research are expected to be implemented in the design and production of energy-efficient motors with high levels of energy efficiency IE1 and higher. Previous work has investigated the balance of energy losses and detailed the mechanical losses incurred by active ventilation and the impact of these losses on the energy efficiency of the motor.

Expected practical results of the work. The expected practical results are the implementation of research results in the design and manufacture of energy efficient engines with a high level of energy efficiency (IE3, IE4). Finally, we note that the relevance of the topic is confirmed by actively published research, as well as current international technical regulations and standards. The implementation of the research is fully in line with the global trend towards energy saving by improving the design of electric motors. Studies are planned to optimize its thermal state to improve consumer qualities. Currently, the problems of optimizing the balance between the thermal state and energy efficiency of electric motors have not been solved, and their solution is an vital important task.

Preliminary results of the work. Using a new approach to the design of energy-efficient motors, electromagnetic calculations and calculations of the motor thermal field were performed, on the basis of which a prototype of an experimental electric

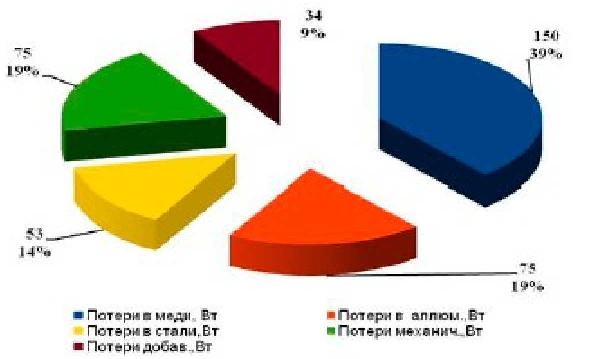

Fig.5 Typical distribution of losses in the size 80A2 (1.5kW, 3000rpm)

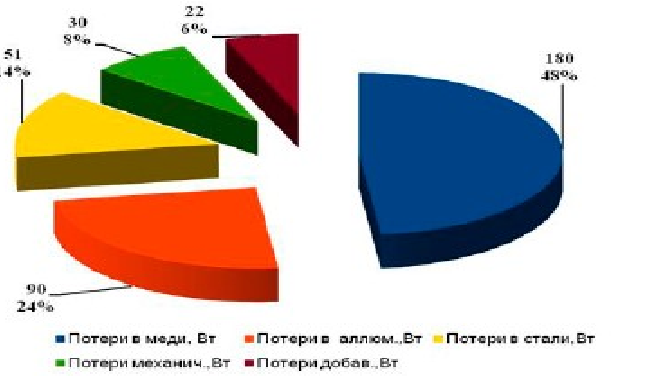

Fig.6 Typical distribution of losses in the size 80A4 (1.1 kW, 1500 rpm)

motor was developed to confirm the correctness of the chosen design direction.Shown is an example of a 2 pole motor of size 71(1.1kW, 3000rpm). (fig.5-8).

In accordance with the previously obtained test data of mechanical losses in bearings and with different greases for the experiment was chosen bearings type 6204.Z and grease LITOL-24 instead of previously used 6204.2RS and grease LZ-31. During the experiment the external fan and cooling conditions were not changed.

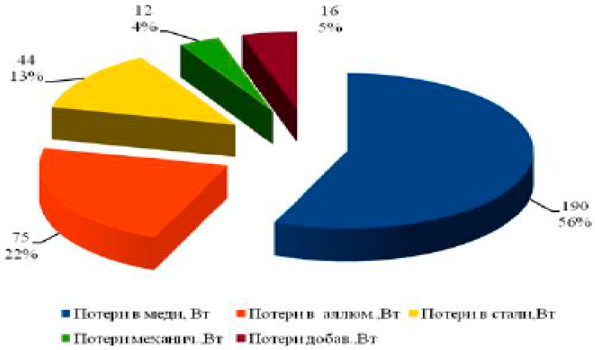

Fig.7 Typical distribution of losses in the size 80A6 (0.75kW, 1000rpm)

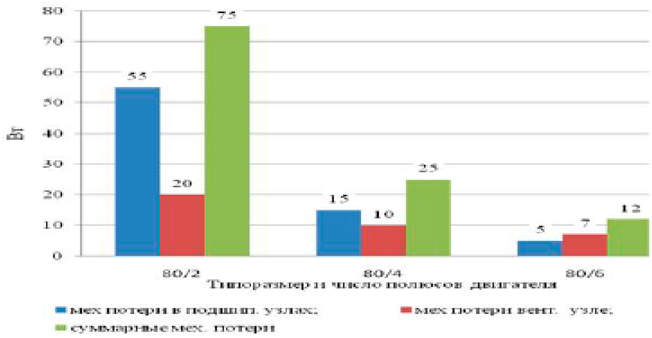

Fig.8 An average numbers on the distribution of losses in bearing and fans of size 80A with 2,4,6 pole.

The results of the experimental verification and tests are shown in the table below. The test results showed that the share of total mechanical losses was reduced by 53.6%, Accordingly, the total motor losses decreased from 220 W to 198 W, which increased the motor efficiency by 0.018 points (from 0.773 to 0.791 points).

Table 1.

Result of test.

	Serial electric motor AIR71A2 with bearings 6204.2RS bearings and LZ-31 grease	The experimental sample AIR71A2 with 6204.Z bearings and LITOL-24 grease
Total frictional losses, W	41	19
Frictional losses in the motor's fan, W	10	10
Frictional losses in bearings, W	31	9

The temperature of the hottest point at the bearing location was steadily reduced by 4 degrees, which generally improved the picture of temperature distribution on the surface of the bearing rail of the motor. Taking into account the increase in efficiency of the motor due to the reduction of losses in the bearings, this makes it possible to further reduce ventilation losses while maintaining the temperature state of the serial motor. All this means that it is possible to economically and significantly increase the efficiency of the motor at the expense of mechanical losses while improving or maintaining the original temperature state.

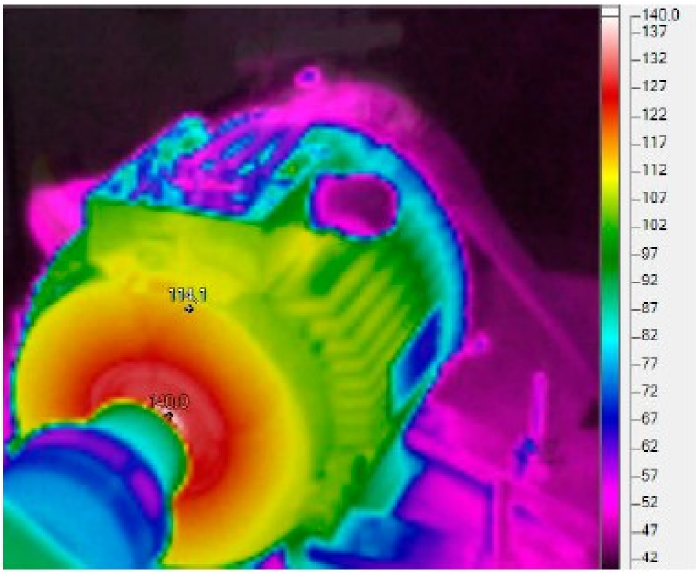

Fig.9 Basic temperature state of the serial motor (size 71A2, 1.5kW,3000rpm),F

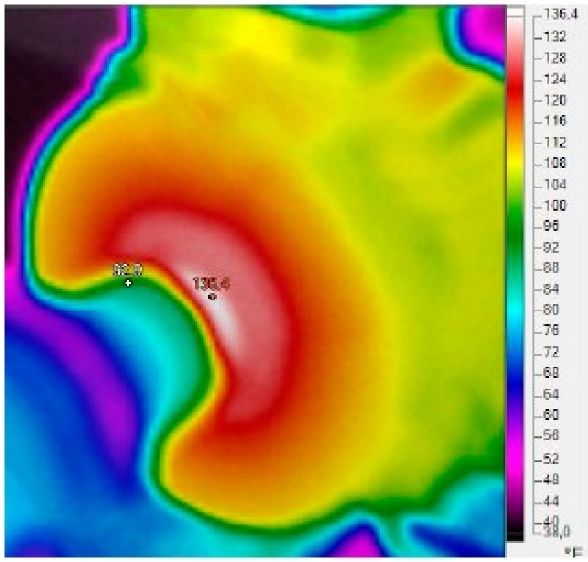

Fig.10 Basic temperature state of the experimental motor (size 71A2 1.5kW,3000rpm),F

Conclusions. Reduction of mechanical losses in bearing units for motors is an effective means to increase efficiency. At realization of the given recommendations in designs of energy-efficient motors, further reduction of mechanical losses in motors of general industrial series is possible at the expense of modernization of ventilation units. The test results confirm the correctness of the chosen direction of research and design, which indicates the need to deepen research and expand the experiments. The work continues in the direction of improving active and passive motor cooling schemes.

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