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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

DEVELOPMENT AND RESEARCH OF THE CONSTRUCTION OF THE ADJUSTABLE ASYNCHRONOUS MOTOR

Speciality:	3340.01 "Electrical systems and complexes"
Field of science:	Techniqal
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GENERAL DESCRIPTION OF WORK

Relevance of the topic:

With the passage of time in industry, in agriculture, in everyday life and in the transportation industry, the progress in reliability, accuracy and control is important in the design of the necessary equipment, in work, in the regulation of torque and speed of rotation. In their work, for the optimal flow of the technological process, the question of frequency regulation of the speed of rotation of the working bodies is raised. Regulation of the rotation speed of the working element in all areas of the national economy is a key condition. For example, the round part on the lathe should be changed at the cutting point so that the speed in the cutting area is approximately constant, which improves the quality. It is necessary that the speed in the machine spindle be changed. This change may also occur due to the nature of the details, since the nature of the work may be rough or clean; this may include a change in the physical and mechanical nature of the parts used, changes in cutting, etc. There are many such examples. Examples of mechanisms required by regulation include rolling stock, paper making, lifting, transport, agricultural, textile and other mechanisms. In all cases, the regulation of rotation speed allows the efficient use of production mechanisms, create optimal working conditions and reduce energy consumption.

Currently, there are systems that operate on the principle of controlling the speed of rotation, where the frequency of the voltage of the motor source is adjusted accordingly. The principle of creating accurate proportionality between the voltage value and the rotation speed on the motor shaft using high-performance voltage modifiers (thyristor voltage regulators, etc.) creates the basis for a new system in the proposed design.

With the help of an electric motor, precise control of the frequencies of rotation of the organs of mechanisms is carried out, regardless of the magnitude of the torque on the shaft and in accordance with the requirements of the working body. An analysis of the mechanical characteristics of the motors shows that a change in their speed of rotation can be associated with changes in electrical circuits (resistance) and supply voltage (voltage, frequency). The rotation of the electric motor causes a difference in the moment determined by the change in the first factor - the circuit or power source.

As electrical machines develop, it is difficult to achieve material savings at a given level of energy performance. In the modern world, the resources for improving the properties of electrical steel, the quality of copper filling in the slot, thermal insulation resistance and the rational choice of the geometric dimensions of the active parts are already exhausted. Under these conditions, the role of intensification of cooling intensifies. This is especially true for IP 44 series asynchronous machines. Due to the low rotation speeds in these machines, the amount of energy loss increases.

Because asynchronous machines control the speed of rotation, the amount of cooling air decreases as fan performance decreases. This leads to a decrease in the torque of the machine, which leads to a sharp increase in the specific gravity of the material. If we design the fan at lower rotational speeds, its useful coefficient of performance will sharply decrease with an increase in the adjustment range.

When designing the appropriate engines for such purposes, the following issues must be considered: electromagnetic compatibility of the engine with control devices, especially the stability of voltage regulators in terms of parameters, the choice of engine power, the effect of additional losses, torque on the cost of permissible overloads, etc.

The design features used are important because of their simplicity, cheapness and ease of handling. The equipment used in the control system is small - it is easy to manage.

Purpose of work:

A key element in the implementation of the above factors is the creation of an electrical machine that provides them with mechanical energy that fully meets the requirements required for the purpose of the dissertation. This scientific work provides a state of the art relevance in terms of the use of the elements.

The purpose of the work is to develop a high-performance two-rotor asynchronous motor that can accurately control the rotational speed of the mechanisms involved in the technological process in a wide range.

In accordance with the purpose of the dissertation, the following main issues were resolved:

1. Generalized design scheme.
2. Adaptation of parameters of loading and adjustment of the engine.
3. Checking how torque can be obtained at different speeds depending on the voltage value.
4. Computational and graphic determination of currents and their proportions, providing a torque in the frequency of rotation.
5. Calculation and research of the ratio of rotation speed and torque at different values of the rotor resistance.
6. Analysis and calculation of engine temperature.
7. Comparison of the volume of ventilation and heat and calculation of the ratio between them.

The scientific novelty of the work:

1. In the developed new AM, the creation of a smooth relationship between the torque on the shaft and the rotational speed
2. Introduction of the rotor resistance into the system of the projected IM in the form of a complete structure c.
3. Maintaining a high level of ventilation even at low speeds.
4. Complex solution of theoretical problems of several electromechanical processes current in a new AM with a multi-element rotor.
5. Realization of an effective mode of operation of an asynchronous machine using constructively obtained methods.

Basic provisions for protection:

1. Provide a complete schematic representation and analysis of the new two-rotor design.
2. To solve theoretical problems of electromechanical processes in two-rotor IM.
3. Analyze the process of heat release and distribution due to losses in individual elements, depending on the torque on the shaft.
4. Achieve efficient development of a new ventilation system that carries out the process of heat removal from the machine and ensure full design performance.
5. Determine the losses in the new blood pressure and develop a methodology for solving design problems.

Justification and integrity:

It is based on the fundamental laws of electromechanics, including the theory of energy conversion: magnetic, electrical and thermal processes. Here, the progress of the tuning process, the accuracy and correctness of the process, and the analysis of errors in the tuning area are key.

The practical value of the work:

For optimal movement of the technological process, it is important to regulate the speed of rotation of the working bodies. By adjusting the rotation frequency of mechanisms, you can achieve their optimal use, create a technologically optimal operating mode and reduce energy consumption. The newly designed asynchronous motor allows a variety of control methods.

The use of the developed design with the above objects has a comprehensive positive effect on the elements of the system, since it leads to an increase in the efficiency of the device when regulating speed and torque in small volumes and, in general, reduces overall costs.

Implementation of work results:

The variable induction motor is offered for use in various industries and agriculture. The design patent for a two-rotor asynchronous motor is the basis for the implementation of the thesis. The patent passed initial polls and received a positive response.

Work approbation:

The main provisions and results of the dissertation were reported and discussed:

1. Respublika Elmi-Praktiki Konfransında MDU, Mingəçevir, 6-7 dekabr 2013.
2. Respublika Elmi-Texniki Konfransında MDU, Mingəçevir, 28-29 noyabr 2014.
3. Beynəlxalq Elmi-Texniki Konfransında SDU, Sumqayıt, 27-28 oktyabr 2015.
4. Respublika Elmi Konfransında, MDU, Mingəçevir, 27-28 noyabr 2015.
5. Respublika Elmi Konfransında, MDU, Mingəçevir, 23-24 dekabr 2016.
6. Magistrantların XVII Respublika Elmi konfransında SDU, 11-12

may 2017.

7. X Международная Научно-Практическая Конференция Молодых Ученых, УГНТУ, Россия, Уфа, 14 апреля – 19 мая 2017.

8. Respublika Elmi Konfransında, MDU, Mingəçevir, 7-8 may 2018.

9. Respublika Elmi Konfransında, SDU, Sumqayıt, 30-31 may 2019.

Publications:

The author published 10 articles (three of them abroad) and 9 conference materials (one abroad).

The structure and scope of work:

The dissertation consists of an introduction, four chapters, conclusion and appendices. Also includes 31 photographs and a list of references.

SUMMARY OF WORK

At the beginning of the dissertation, the relevance of the topic was substantiated, the main goals and objectives of the study were determined, the scientific novelty of the work, its practical significance, the main provisions of the defense and a summary of the main sections of the dissertation are given.

The first chapter examines and introduces the improved structure of a two-rotor induction motor with a rotational speed, adjusted based on a comparative analysis. The design of the AD with two rotors is an electric motor with an adjustable speed of rotation and high energy characteristics. The scope of the engine is defined. It should be noted that the accuracy of any incidental adjustment price at the request of devices, household appliances, industrial units that require adjustment of torque and speed increases the demand for the designed engine.

The engine design is given (fig. 1). The design is based on an asynchronous motor with a modern squirrel-cage rotor [3, 4, 9, 10, 11, 12, 14, 16]. The rotor surrounded by the stator was replaced by two rotors: a working one and an additional one (Fig. 1).

The working rotor is designed to operate in a wide range of rotation speeds depending on the voltage of the stator, and the additional rotor works so that the machine completely cools down within wide limits.

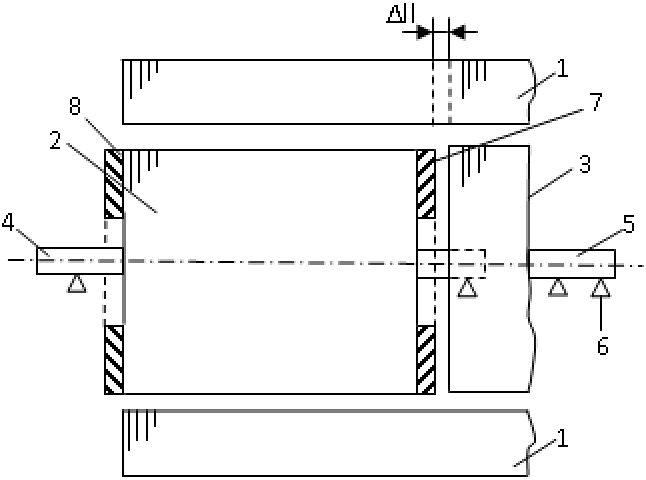


Fig. 1. Engine design

1- Stator; 2 - working rotor; 3 - additional rotor; 4 - shaft of the working rotor; 5 - shaft of the additional rotor; 6 - bearings; 7 - short-circuited ring (made of copper); 8 - short-circuited ring (from high-strength metal); Δl - air gap

For a clear presentation of the designed machine, sections of structural elements along length and width are given, where the stator and rotor elements are clearly marked [16].

The structural regions of shear, the effects of the cooling system and other elements are clearly marked along both axes (Fig. 2).

The working and auxiliary rotors are completely independent, because they are connected only mechanically, one shaft is attached to the other using the second bearing on this shaft. The working and additional rotors have only a magnetic connection, so the operation mode is created based on internal parameters.

The working rotor will rotate at a certain rotation speed, depending on the rated voltage of the stator winding (to obtain the required speed of rotation, the stator winding can be designed for full or lower rated voltage). To change the rotation speed over a wide range, this voltage is changed. The fused copper material is placed in grooves open along the outer diameter of the working rotor, which is assembled from steel sheets 0.5 mm thick. The ends of the rotor winding from the side of the additional rotor emerge in the form of a short-circuited ring and form a complete structure. The outer ends of the working rotor winding, on the other hand, are made of fechral having a high resistance, and therefore, by changing the voltage supplied to the stator windings, it is possible to change the speed of rotation of the working rotor in the range of 1:10.

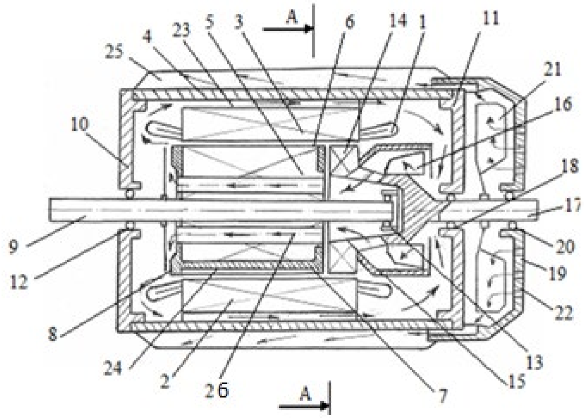


Fig. 2. The design of the car.
1 - stator windings; 2 - stator magnetic circuit; 3 - stator; 4 - housing; 5 - working rotor; 6, 24 - copper winding of the working rotor; 7 - a short-circuited copper ring; 8 - a short-circuited ring of fechral; 9 - shaft of the working rotor: 10,11 - bearing shields; 12,13 - bearings; 14 - additional rotor; 15 - ventilation ducts; 16-ventilation blades; 17 - an additional shaft; 18 - bearing; 19 - bearing shield; 20 - bearing; 21 - fan; 22 - ventilation ducts; 23 - ventilation ducts; 25 - body ribs; 26 - ventilation ducts of the rotor

Speed control in the engine design is based on a change in voltage supplied to the stator (Fig. 3).

The relationship between the torque on the motor shaft and temperature was investigated. When maintaining engine power in the process of reducing the speed of rotation of the working rotor, it is impossible to increase the temperature by changing the losses, since the cooling system at all speeds prevents the temperature in the engine from rising. Cooling air is sufficiently pumped at all rotation speeds, regardless of voltage, and the elevated temperature is transferred to the external atmosphere.

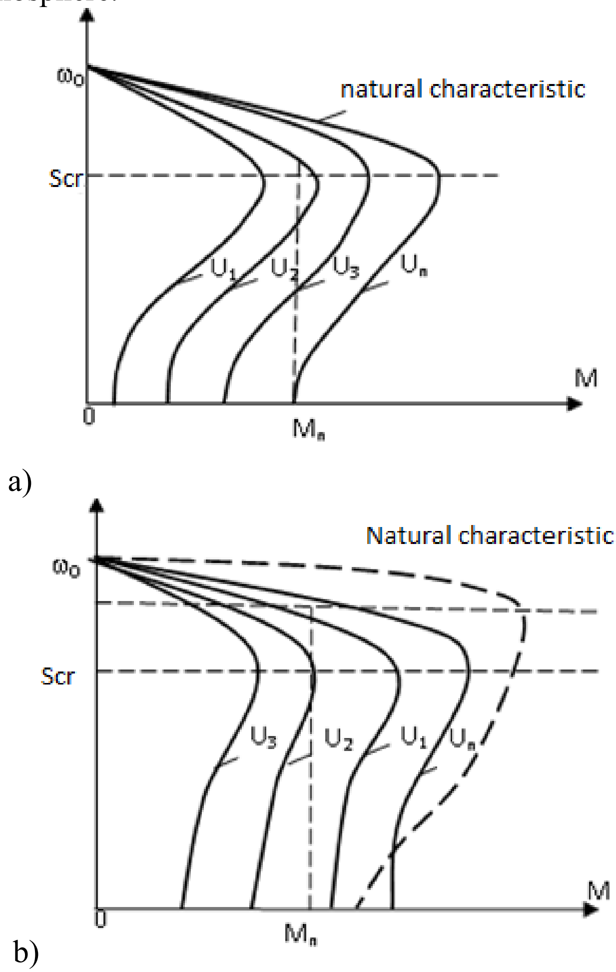


Fig. 3. Mechanical characteristic asynchronous machine with voltage reduction

a - rotation speed - ω on the shaft of a normally short-circuited rotor; b - on the designed machine with a high resistance of a short-circuited ring

The choice of materials of the working rotor in the overall design gives this the basis. Increasing the resistance of the rotor in the direction of air flow from the rotor is carried out using a short-circuited ring made of a material with high resistance - fechral. According to the machine replacement scheme, an increase in the active resistance of the rotor allows you to adjust the speed of rotation.

The stator magnetic field that occurs when voltage is applied penetrates through the magnetic circuit of both the working rotor and the additional rotor. Both rotors generate a rotating magnetic field. There is only one mechanical connection between the main and additional rotor - the bearing. Both rotors are independent of each other.

The connection between the torque on the motor shaft and temperature was investigated. By maintaining, the engine power in the process of reducing the rotor speed, it is impossible to increase the temperature by changing the losses, since the cooling system at all rotation speeds prevents the temperature in the engine from rising. Cooling air is sufficiently pumped at all rotation speeds, regardless of voltage, and elevated temperatures are transferred to the external environment - the atmosphere.

The choice of materials in the overall design of the working rotor winding is based on this. The increase in rotor resistance is associated with the establishment of a short-circuiting ring made of a material with high resistance - fechral in the direction of air flow from the rotor. According to the machine equivalent circuit, increasing the rotor's resistance allows you to adjust the speed of rotation.

The stator magnetic field that occurs when voltage is applied to the stator windings penetrates through the magnetic circuit of both the working rotor and the additional rotor. Both rotors generate a rotating magnetic field. There is only one mechanical connection between the main and auxiliary rotor - the bearing. Both rotors are independent of each other [7].

The working rotor will rotate at a certain rotation speed, depending on the rated voltage of the stator winding. To regulate the rotation speed over a wide range, the voltage value changes, and therefore the critical slip will change in proportion to the active resistance of the rotor r'_{2}:

$$S_{cr} = \frac{c_1 r_2^{'}}{\sqrt{r_1^{'} + \left(x_1 + c_1 x_2^{'}\right)^2}}$$

Due to the active resistance, the value of the critical moment with the maximum value of the torque also increases.

Induction motors can more effectively control the speed of rotation by changing the value of the stator voltage. For this, an autotransformer, a thyristor voltage regulator -TRN, and other methods can be used [17].

TRH has several advantages over other regulators (autotransformer, saturated inductor, etc.): high-speed ability, low load, low cost, tough and smooth characteristics. In a three-phase circuit, two thyristors are connected in parallel to each phase of the circuit, which allows the load current to flow through the network over two half-periods at a voltage of U1.

Using TRH, you can adjust the voltage within Unom - 0. When the stator voltage is non-sinusoidal, using TRH is more beneficial in machines with a high critical slip value.

The second chapter discusses the process of placing the primary and secondary rotors in the design of the machine. With a known power, the power of the additional rotor is determined: in this case, the force applied to the ventilation system at normal power is calculated, and this force is calculated by the length of the stator package, which is considered the length of the working, additional rotor and air gap, which is less than one or two millimeters. As a result, the length of the active rotor makes up a difference of several millimeters, which is added in the direction of the short-circuited ring when calculating the total length. The working rotor is specially made of individual materials, so that these elements are useful in regulating the speed of rotation. The rotor magnetic system matches the design of mass-produced machines. Two parts of the rotor winding are designed for normal operation of the machine: the winding itself and the short-circuited ring on one side are made of copper material. Copper has been used to reduce current losses. Another short-circuited ring is made of high-strength material and is attached to the winding by welding [6] .

The rods of a short-circuited ring with high resistance can be made in various designs, depending on the required resistance value. The design shown in Figure 4.a can obtain the necessary resistance by changing the dimensions a1 and a2. Large resistance limits are shown in Figure 4.b. In this case, the necessary resistance can be obtained by changing the thickness of two compartments connected by two grooves a3 and length l.

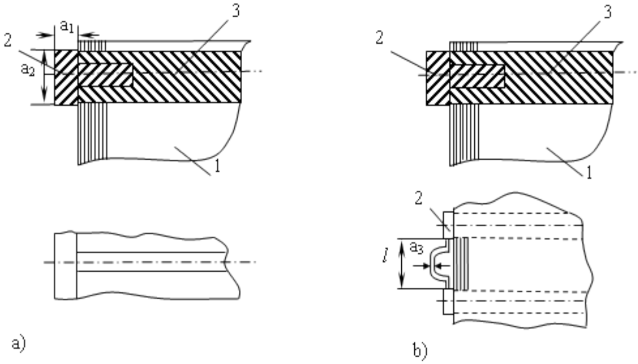


Fig. 4. High Resistance Short-Circuit Rings
1 - magnetic circuit; 2 - short-circuited ring with high resistance; 3 - copper rotor winding

The main characteristic is the torque characteristics, for which some parameters of the stator and rotor must be accurately calculated.

These parameters are the active and inductive resistances of the stator and rotor, the calculation of which is as follows[1]:

1. The active resistance of the stator winding

$$r_1 = \rho_{115}\frac{L_1}{q \cdot a} = \frac{10^{-4} \cdot 80{,}86}{41 \cdot 2{,}454 \cdot 2 \cdot 210^{-6}} = 0{,}402 \text{ Ohm}$$

2. The active phase resistance of the rotor winding

$$r_2 = r_r + \frac{2r_{sc}}{\Delta^2} \quad (1)$$

$$r_2 = r_r + \frac{r_{sc1} + r_{sc2}}{\Delta^2} \quad (2)$$

Here, both short-circuiting rings made of the same material with

[1] Копылов Н.П. Проектирование электрических машин. Москва, 2014, с.75-115

resistance r_{qq}, shown in (1), refer to serial machines, and (2), where r_{kz1} is the resistance of a short-circuited ring made of copper, rkz2 is the resistance of a short-circuited ring made of fechral belong to the new design.

To select the characteristics of the designed machine, the parameters must have different values so that the characteristics for any desired rotation speed are obtained. For this, it is necessary to change the active resistance of the rotor in order to characterize each resistance.

First of all, the parameters specified in (2) should be known for a 15-kW engine. To do this, calculate the resistance of the working rod of the rotor *rscr*, copper short-circuited ring r_{kz1} and the resistance r_{kz2}

$$r_2 = \rho_{115}\frac{l_2}{q_r} = \frac{1}{41}\cdot 10^{-6}\frac{0,11}{191\cdot 10^{-6}} = 14\cdot 10^{-6}\,Ohm$$

$$r_{sc1} = \beta_{115}\frac{\pi D_{sc}}{z_2\,q_{sc}} = \frac{10^{-6}}{41}\cdot\frac{\pi\cdot 0,144}{38\cdot 460\cdot 10^{-6}} = 0,63\cdot 10^{-6}\,Ohm$$

We take into account resistivity:

for copper, 0.0175 $\frac{om\cdot mm^2}{m} = 1,75\cdot 10^{-8}\,Om\cdot m$;

for fechral 1.2 . $\frac{om\cdot mm^2}{m} = 1,75\cdot 10^{-8}\,Om\cdot m$.

With the same size of both short-circuited rings, the resistance of the fechral ring will be k_f= 120/1.75 = 68.6 times greater.

For the same accepted size,

$$r_{sc2} = r_{sc1}\cdot k_f = 0,63\cdot 10^{-6}\cdot 68,6 = 43,22\cdot 10^{-6}\text{Ohm}$$

By reducing the k_f value by 50%, we get the following - relatively small values.

$$r_{sc2} = 21,61;\ 10,805;\ 5,355;\ 2,7\cdot 10^{-6}\text{Ohm}$$

Based on the expected values, we calculate the total active resistance of the rotor winding:

$$r_2 = r_c + \frac{r_{sc1}+r_{sc2}}{\Delta^2} \quad (3)$$

The computational operation is designed for various values of rkz2 in order to obtain the mechanical characteristics of the machine and consider suitable characteristics. Calculations are made in the following sequence. If we write expression (3) according to acceptable values, we can obtain the following (the recorded numerical values are intended for the designed asynchronous machine with a power of 15 kW):

$$r_2 = 14 \cdot 10^{-6} + \frac{0{,}063 \cdot 10^{-6} + r_{sc2}}{0{,}329^2}$$

The obtained values of r2 from table 1 are reduced to the number of turns of the stator windings.

Table 1.

Rotor winding resistance, taking into account the resistance of the short-circuited ring

$r_{sc2}, 10^{-6} Ohm$	43,22	21,61	10,805	5,355	2,7
$r_2; 10^{-6} Ohm$	453	238	128	73	33,3

$$r_2' = r_2 \frac{4m(\omega k_{d1})2}{z_2} \quad (4)$$

The calculations are given in table 2.

Table 2.

The values of the resistance of the rotor winding, reduced to the stator

$r_2, 10^{-6}$ Ohm	453	238	128	74	33,3
r_2'; Ohm	15,4	9,0	5,31	3,51	1,68

The most important operating characteristics of the machine are considered (Fig. 5). Various design characteristics of the working rotor were calculated: characteristics of the current and stator moment, when the rotor shaft is completely copper, and various characteristics of the moment in the case of a short-circuit ring with high resistance (Fig. 6.) [11].

The machine heating mode works as follows: the amount of heat released during the operation of the working and auxiliary rotors must enter the machine body through the stator zone and from there into the atmosphere.

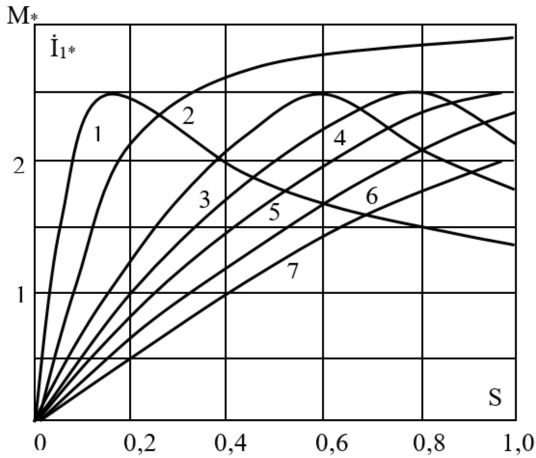


Fig. 5. Engine start characteristics
. 1 - stator current in the case of a copper winding of the rotor; 2-moment characteristics in the case of a copper winding of the rotor; 3-7 moment characteristics at different values of the rotor resistance (table 2.3.) With one short-circuiting ring. Of the high-resistance dielectric.

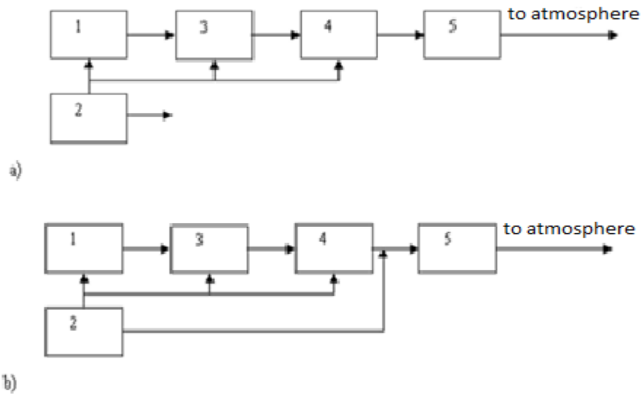
Table 3.

Mechanical characteristics of the machine depending on the resistance of the short-circuited ring $M_* = f(r_2')$

Short circuit resistance r_2'		Sliding					Critical sliding
		1,0	0,8	0,5	0,2	0,1	0,6
1,68	M_*	2,0	1,75	1,2	0,51	0,27	0,8
3,51	M_*	2,25	2,05	1,48	0,62	0,35	1,0
5,31	M_*	2,5	2,23	1,70	0,75	0,45	-
9,0	M_*	2,25	2,5	1,9	1,0	0,55	-
15,4	M_*	1,75	2,25	2,45	1,45	0,8	-

The effect of the ventilation system is the same as in conventional serial machines (Pic. 6a): the heat flux from the rotor passes through the air gap through the magnetic conductor of the rotors into the stator housing, from there into the steel housing, and finally into the atmosphere through the air flow (external fan). In the new design, this process, in a suitable structure, enters the steel body (Pic. 6b) and from there is transferred to the atmosphere [11].

In the machine, a diagram of heat fluxes is given, so that most of the heat generated by the rotors of the structure is transferred directly to the atmosphere (without entering the stator) into the atmosphere (Fig. 6) [11].



Pic. 6. Heat flow diagram
a) serial engine, b) two-rotor engine with a wide range of regulation
1-stator winding, 2- working and ordinary additional rotors, 3- slot insulation, 4- stator steel, 5- case.

This process flow prevents part of the heat from flowing from the rotors into the air gap and into the stator insulation. In this case, the temperature in the stator insulation will be reduced, which will make it possible to increase the load on the machine. The efficient design of the air ducts on the working rotor accelerates this positive process. The developed design extends the applications of such electrical machines.

Calculations of losses of the designed machine and on their basis, efficiency were carried out c.u.a. (coefficient useful actions) engine.

In the sections where the calculations are made, many parameters were adopted with some adjustments, as necessary, based on the instructions for serial machines.

1. The main losses of machine steel:

$$P_{m.st.}=P_{1,0/5,0}(\frac{f_1}{50})\beta(k_{da}B_a^2 m_a+k_{dz}B_{z1}^2 m_{z1}=$$
$$=2,6(1,6\cdot1,652\cdot16,78+1,8\cdot1,812\cdot5,27=270,8\ W$$

$$m_a=\pi(D_a-h_a)h_a l_{c1}k_c\gamma_c=$$
$$=\pi(0,272\text{-}0,0217)\cdot0,0217\cdot0,13\cdot0,97\cdot7,8\cdot103=16,78\ kg$$

$$h_a=0.5(D_a\text{-}D)\text{-}h_y=0,5(0,272-0,185)-0,0218=0,0217\ m$$

$$m_{z1}=h_y\cdot b_{y\ average}\cdot z_1\cdot l_c\cdot k_c\cdot\gamma_c=$$
$$=21.8\cdot10^{-3}\cdot4.8\cdot10^{-3}\cdot48\cdot0.13\cdot0,97\cdot7,8\cdot10^3=4,94\ kg$$

2. Surface rotor losses:

$$P_{sr}=p_{sr}\cdot(t_1-b_{ş2})\cdot z_2\cdot l_{c2}=$$
$$=242,4\cdot15,2\cdot10^{-3}\cdot38\cdot0,13=18,2\ W$$

$$P_{sr}=0,5R_{av}(\frac{z_1n_1}{10000})^{1,5}\cdot(B_{av}\cdot t_1\cdot10^3)^2=$$
$$=0,5\cdot1,5(\frac{48\cdot1500}{10000})^{1,5}\cdot(0,338\cdot12,1)^2=242,4\ W/m^2$$

Surface induction:

$$B_{or}=\beta_{av}\cdot k_\delta\cdot B_\delta=0,37\cdot1,22\cdot0,749=0,338$$

3. Loss of ripple in the teeth of the rotor

$$P_{pul.2}=0,11(\frac{z_1n}{1000}B_{pul.2})^2 m_{z2}=$$
$$=0,11\left(\frac{48\cdot1500}{1000}\cdot0,131\right)^2\cdot7,77=69,1\ W$$

Weight of steel - rotor teeth:

$$m_{z2} = z_2 \cdot h_{z2} \cdot b_{z\,aver.} \cdot l_{st2} \cdot k_c \cdot \gamma_c =$$
$$= 38 \cdot 32 \cdot 10^{-3} \cdot 6{,}5 \cdot 10^{-3} \cdot 0{,}13 \cdot 0{,}97 \cdot 7800 = 7{,}77\ kg$$

4. The total number of additional losses in steel:

$$P_{ad.s.} = P_{s2} + P_{pul.2} = 18{,}2 + 69{,}1 = 87{,}3 \text{ W}$$

5. Total steel loss

$$P_{st} = P_{a.base} + P_{a.extra} = 270{,}8 + 87{,}3 = 358{,}1 \text{ W}$$

6. Mechanical losses:

$$P_{mech} = k_t \left(\frac{n}{10}\right)^2 D_a^4 = 0{,}95 \left(\frac{1500}{10}\right)^2 \cdot 0{,}272^4 = 117 \text{ W}$$

7. Additional losses in nominal mode:

$$P_{ad.n.m.} = 0{,}005 P_{1n} = 0{,}005 \frac{P_{2н}}{\eta} = 0{,}005 \cdot \frac{1500}{0{,}88} = 85{,}4 \text{ W}$$

The efficiency η=0.88 is taken as an approximate value for machines with a series of 10-30 kW.

The total losses for calculating the operating coefficient of the designed machine are as follows [15]:

$$\Sigma P = P_с + P_{mech} + P_{extra} + P_{e1} + P_{e2}$$

8. Electric losses in the stator winding:

$$P_{e1} = 3 \dot{I}_1^2 \cdot r_1 \cdot 10^{-3} = 3 \cdot 29^2 \cdot 0{,}402 \cdot 10^{-3} = 1{,}05\ kW$$

9. Electrical losses in the rotor winding:

$$r_2 = r_r + 2 \frac{r_{k.l}}{\Delta^2}$$
$$r_2 = r_r + \frac{r_{kl.m}}{\Delta^2} + \frac{r_{kl.f}}{\Delta^2}$$
$$r_r = \beta_{115} \frac{l_2}{q_r} = \frac{10^{-6}}{41} \cdot \frac{0{,}13}{167 \cdot 10^{-6}} = 19{,}8 \cdot 10^{-6} \text{ Ohm}$$
$$r_r = \beta_{115} \frac{\pi D_{sc.aver.}}{z_2 \cdot q_{sc}} = \frac{10^{-6}}{41} \cdot \frac{3{,}14 \cdot 0{,}147}{38 \cdot 595 \cdot 10^{-6}} = 0{,}49 \cdot 10^{-6} \text{ Ohm}$$
$$r_{scf} = \beta_{115} \frac{\pi D_{sc.aver.}}{z_2 \cdot q_{sc}} = \frac{10^{-6}}{7{,}58} \cdot \frac{3{,}14 \cdot 0{,}147}{38 \cdot 600 \cdot 10^{-6}} = 2{,}7 \cdot 10^{-6} \text{ Ohm}$$

The total resistance of the rotor winding:

$$r_r = r_{rod} + r_{sc.c} + r_{sc.f} = (19{,}8 + 0{,}49 + 2{,}7) \cdot 10^{-6} =$$
$$= 22{,}99 \cdot 10^{-6} \approx 23 \cdot 10^{-6} \text{ Ohm}$$

The rotor resistance value is given to the number of turns of the stator winding:

$$r_r' = r_2 \frac{4m(\omega \cdot k_{d1})^2}{z_2} = 23 \cdot 10^{-6} \frac{4 \cdot 3(112 \cdot 0{,}957)^2}{38} = 0{,}83 \text{ Ohm}$$

Electric losses in the rotor winding:

$$P_{e2} = 3 \cdot \dot{I}_1^2 \cdot r_2' \cdot 10^{-3} = 3 \cdot 29^2 \cdot 0{,}83 \cdot 10^{-3} = 0{,}213 \cdot 10^{-3} \text{W}$$

Total machine loss:

ΣP=Pst+Pmech+Pe1+Pel2+Pel=
=358,1+117+1050+213+87=1825,1 W
ΣP = 1,825 kW

Machine efficiency:

$$\eta = 1 - \frac{\Sigma P}{P_1} = 1 - \frac{1{,}825}{15} = 1 - 0{,}121 = 0{,}879$$

The fact that the obtained value is slightly lower (from 0.003 to 0.005) than that of serial engines indicates that the engine is specially controllable, and this value can be considered a high indicator.

The third chapter examines the dependence of engine power and torque on frequency. The proportionality of the force to the cube of the frequency and the momentum of the squared frequency is confirmed. For the entire frequency range, this problem was resolved. For other types of power, the dependence on the rotation speed is also considered and justified[2] [14].

Changes in frequency, current and voltage in the workflow that correspond to changes in load and torque can be divided into three phases:

1. The choice of the nominal design mode;
2. Search for acceptable solutions;

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[2] Тубис Я.Б., Фанарь М. С., Нарынская В.М., Зезюлина Л. М. Методы исследования и анализ теплоотдачи асинхронных двигателей. М.: Информэлектро, 1981

3. Search for the optimal solution.

At the first stage, the dependence of power or torque on the rotation speed is analyzed. Consider two states: fan load and stable power mode.

In the first case, the power is proportional to the cube of the frequency, and the moment to the square (Fig. 7.a).

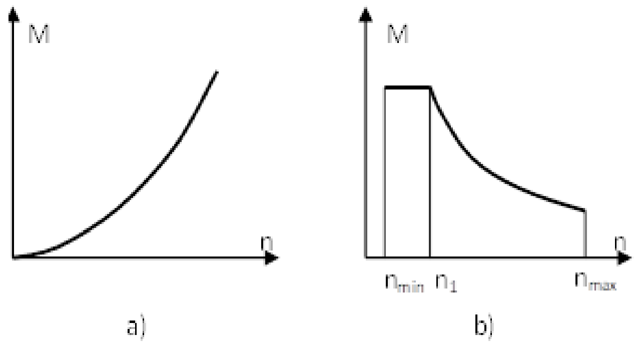
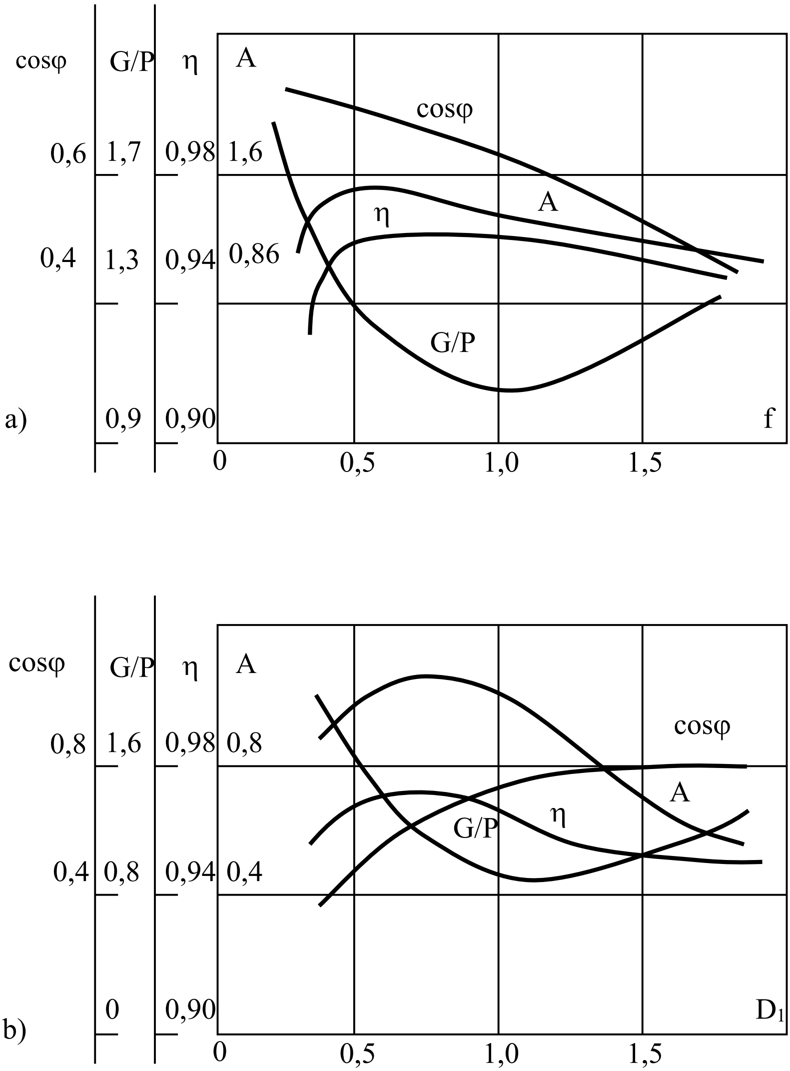


Fig. 7. The main types of graphs of an induction motor in the frequency control mode:
a - fan characteristic, b - load characteristic

The choice of the optimal dependence U (f) makes it possible to obtain sufficient values. for the whole range. The load diagram for electric drives of moving devices is shown in 7.b. In the interval nmax-n1, P = const, and in the interval n1-nmin.M = const. To achieve the diametral stiffness and stability of the rotor, the restrictions must be included in the nmax mode. When heating, the restrictions are switched on in the n1 mode, which corresponds to the maximum current and maximum magnetic flux.

At the second stage, the process of selecting the optimal nominal frequency and the corresponding basic dimensions is performed. One of the most common criteria is minimum weight.

In fig. 8.a. dependences of the mass of the active material on the frequency are given for a given diameter value. A choice was made of the optimal nominal frequency and the corresponding values of the main measurements (Fig. 8).



Pic. 8. The dependence of the mass of the induction motor and other indicators:
a) for D = const of frequency and b) for f = const of diameter

A block diagram system was considered in which the size of the active zone (induction and current density) were chosen at the permissible boundaries. When developing the engine design, minimum cost values were also considered.

Comparing the prices of machines in a wide range of capacities, this problem was solved by the design of two rotary machines. When choosing the size of the machines, economic issues were also resolved. Minimum conditions for accepted prices have been determined. The main dimensions of the designed machine were chosen with minimal cost.

The fourth chapter presents a cooling program for different speeds of rotation, which takes into account the temperature of the machine based on the calculated losses. It was noted that even at low speeds of the working rotor, the ventilation system is very effective. The required level of heating and ventilation modes is set [13, 18, 19].

To calculate the temperatures in the elements, the losses in the working elements of the engine were taken into account. To strengthen the ventilation system in places where losses are most common, the correct placement of the elements was considered[3].

Since the designed machine has a wide range of changes in speed and direction of rotation, the current processes, parameters, and heating resulting from changes in torque are also complex.

Speed control requires the correct design of the cooling system[4]. In the design of an electric machine, the cooling process, the wide rotational speed of the working rotor and the occurrence of variable losses make the cooling process even more complex.

Two rotors are installed, and the additional rotor works with a highly efficient ventilation system regardless of the working rotor. Although the frequency of rotation of the working rotor varies widely, the additional rotor continues to work in asynchronous mode. At minimum speeds of rotation of the working rotor, the speed of the additional rotor can decrease by only a few percent, which will not

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[3] Филиппов И.Ф. Теплообмен в электрических машинах -Л.;Энергоатомиздат, 1986, с. 118-125.

[4] Попов В.И., Ахунов Т.А., Макаров Л.Н. Современные асинхронные машины: Новая Российская серия РА.-М.:Изд-во «Знак», 1999, с. 118-125.

have a significant impact on the operation of the cooling system.

When adjusting the speed of the working rotor, the value of the current J_1 can vary widely. If the working rotor speed is adjusted while the machine is idling, both currents will change. At low speeds, the current of the working rotor will hardly change, and small changes can be considered. When the slip value of the auxiliary rotor changes, the current value along its torque curve will change; in idle mode, this value will not be available for the additional rotor, since its function is to provide ventilation. At different speeds of the working rotor, the speed of the additional rotor will change according to the principle of asynchronous mode with a slight change in slip. The additional rotor is designed in such a way that at the frequency of the lower stage of rotation of the working rotor it will have a slight change from the design value.

In the loaded mode of the working rotor, the auxiliary rotor can change the rotation speed to a small extent, depending on the magnitude of the voltage applied to the stator, depending on the adjustment mode of the machine.

In a projected asynchronous machine with two rotors, the slope of the grooves can also be ignored. Because the skew is usually aimed at reducing magnetic losses, and since the magnitude of these losses is too small in the presented motor, the skew of the rotor slots can only be attributed to high-power asynchronous machines.

The developed two-rotor induction motor can also be manufactured in various operating modes and in the program for changing the direction of rotation of the working rotor. High-quality and well-ventilated ventilation systems must be designed for machines with the same and variable rotation. If the operating mode of the designed machine has two directions of rotation, both internal and external fans must direct air in only one direction. This direction should be in the direction of the working rotor from the additional rotor. The problem is that the copper winding of the working rotor has a heat source - a short-circuit ring with a high resistance, which is located in the opposite direction from the rotor, and a large amount of heat passes through the ventilation system. For this purpose, centrifugal fans (both internal and external) are designed to supply cooling air to the ducts in both directions.

The main purpose of calculating the ventilation of the designed electric machine is the choice of the ventilation scheme as a whole, as well as the determination of the operation of the elements of the air blower, thereby providing the required volume of the cooling medium per unit of time.

The volume of air consumption (flow) is the volume of the medium that passes through the cross section of the duct (duct) per unit of time. It is the volume passing through all parallel ventilation paths per unit of time or across the cross-section of inlet (outlet) distances that applies to the entire electrical machine.

The flow rate Q is expressed in cubic meters per second and has a simple relationship with the average speed ω of the duct in the duct (4):

$$Q=\omega S \quad (5)$$

where S is the channel cross-sectional area.

The ventilation system was developed as a freely constructive scheme: in structural elements, ventilation passages were designed taking into account the volume of heat, regardless of the speed of rotation, cooling works efficiently, that is, regardless of the operating mode of the engine, a constant speed of rotation of the additional rotor contributes to this.

The ventilation system provides the direction of the ventilation elements in only one direction, depending on which direction the rotor rotates. Stability of ventilation is achieved through the use of both internal and external fans of the machine[5].

Centrifugal fans are designed for two-way rotation. Fans are located on the second central axis of the machine and are driven by an additional rotor: the rotation frequency is the asynchronous frequency in the entire control zone.

MAIN RESULTS

When developing a two-rotor induction motor with a wide range of

[5] Невельсон М.И. Центробежные вентиляторы.- М.; Госенергоатомиздат, 1984, с.225-263

precise frequency control and having high electrical performance, the following results were obtained:

1. The functions of the working rotor and the additional rotor inclu ded in the design are informed and the operating principles are clarified [3, 4, 9, 10, 12, 16].

2. When considering the rotation speed, the critical sliding variability is analyzed in accordance with the voltage fluctuations supplied to the stator windings, and rotation speed graphs for changing voltage values are shown [1, 17].

3. The structural characteristics of the working rotor were investigated, the influence of the winding parts on the machine was clarified, and images of a short-circuiting ring with high resistance and its effect on the working process of the machine were given [2, 11, 15].

4. The volume of losses on the working rotor was taken into account among the total losses. It was confirmed that the working rotor has a copper wire, high magnetic conductivity, which helps to reduce losses, and the volume of losses passing through the air space into the stator missiles was compared. Compared to machines of the same power [5, 14].

5. A study is given of the heat sources in the machine and the amount of heat generated, and also indicates the direction of use of the ventilation system [13].

6. The developed design provides an effective ventilation system: the ventilation system provides for the installation of a short-circuited ring with a high resistance, which provides the flow of air-cooling mass in the same direction where the generated heat is transferred directly to the machine body, and not to the rotor volume. This process leads to the fact that in the process of regulating the machine within wide limits, the power removed from the shaft cannot be reduced [18].

7. When the rotor speed decreases, the air necessary for cooling in the process of changing losses (increase or decrease) in one direction or another does not decrease, and the engine is effectively cooled [19].

Despite a slightly modified design of the considered design of an asynchronous machine, its use is very advisable, since it is possible to obtain a wide range of rotational speeds, varying the voltage applied to the stator in several ways, and cheaper than other regulatory systems.

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3. Musayev Z.N., Şıxəliyeva S.Y. Fırlanma tezliyi tənzimlənən asinxron mühərrikin layihələndirilməsində bəzi məsələlər – Respublika elmi - praktik konfrans, MPİ, 6-7 dekabr, 2013, s.107-109.

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5. Şıxəliyeva S.Y. İstismar faktorlarının asinxron mühərriklərin etibarlılıq göstəricilərinə təsiri – Respublika elmi konfrans, Mingəçevir, 28-29 noyabr, 2014, s.105-108.

6. Мусаев З.Н, Шихалиева С.Я. Пути повышения коэффициента полезного действия электрических машин – Республиканская научная конференция, МПИ, 28-29 ноября, 2014, с.49-51.

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8. Шихалиева С.Я., Нагиева М.Г. Эффэктивность двухроторного асинхронного двигателя - Республиканская научная конференция МГУ, Мингечевир, 27-28 ноября, 2015, с.129-130.

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ШИХАЛИЕВА СААДАТ ЯШАР гызы

РАЗРАБОТКА И ИССЛЕДОВАНИЕ КОНСТРУКЦИИ РЕГУЛИРУЕМОГО АСИНХРОННОГО ДВИГАТЕЛЯ

РЕЗЮМЕ

Диссертация посвящена разработке и исследованию конструкции двухроторных асинхронных двигателей, которые могут

точно регулировать скорость вращения механизмов, задействованных в технологических процессах, и обладают высокими энергетическими характеристиками.

Новая конструкция ротора имеет общее представление о короткозамкнутом роторном асинхронном двигателе и принципе регулировки скорости вращения. Дается информация о функциях рабочего и дополнительного ротора, а также разъяснены их принципы работы. При рассмотрении регулирования скорости вращения критическое изменение скольжения анализируется в соответствии с напряжением обмотки статора и анализируются графики скорости вращения для переменных напряжений.

Были исследованы конструктивные характеристики ротора, и объяснялось влияние отдельных частей обмотки ротора на работу двигателя. Были даны изображения короткозамкнутого кольца, имеющего высокое сопротивление и его влияния на рабочий процесс.

В ряду общих вопросов был рассмотрен вопрос об объеме потерь рабочего ротора. По сравнению с машинами той же мощности медный проводник ротора данного двигателя, высокая проводимость в магнитных цепях подтверждают уменьшение потерь и объема их прохода через воздушный зазор к статору.

Были также проведены исследования источников тепла и количества тепла, выделяемого в машине, и направления применения системы вентиляции.

При проектировании обеспечивается эффективная система вентиляции: в системе вентиляции, обеспечивающей такой же поток массы охлаждающего воздуха, короткозамыкающее кольцо с высоким сопротивлением устанавливается так, что тепло не переносится на ротор, а непосредственно на станину. В этом процессе делается вывод о том, что в широком диапазоне регулирования как правило мощь на валу двигателя не подлежит сокращению.

Когда скорость вращения ротора уменьшается, изменение потерь в том или ином направлении не дают возможность уменьшению охлаждающего воздуха и машина всегда эффективно охлаждается.

SHIKHALIYEVA SAADAT YASHAR

DEVELOPMENT AND INVESTIGATION OF THE DESIGN OF THE REGULATED ASYNCHRONOUS ENGINE

SUMMARY

The thesis is devoted to the development and study of the design of Two - rotor asynchronous motors, which can precisely regulate the rotation speed of the mechanisms involved in technological processes and possess high-energy characteristics.

The new design of the rotor has a general idea of a short-circuited rotor asynchronous motor and the principle of rotation speed adjustment. Information on the functions of the working and additional rotors is given, and their working principles are explained. When reviewing the rotation speed control, the critical slip change is analyzed in accordance with the stator winding voltage and the rotation speed graphs for variable voltages are analyzed.

The design characteristics of the rotor were investigated, and the effect of individual parts of the rotor winding on the engine was explained. Images of a short-circuited ring with high resistance and its influence on the working process were given.

In a series of general questions, the question of the volume loss of the working rotor was considered. Compared to machines of the same power, the copper conductor of this engine rotor, and the high conductivity in magnetic circuits, confirms the reduction of losses and the volume of their passage through the air gap to the stator.

Studies have also been conducted on the heat sources and the amount of heat released in the car, and the direction of the ventilation system.

When designing, an effective ventilation system is provided: in a ventilation system providing the same mass flow of cooling air, a short-circuit ring with high resistance is installed so that heat is not transferred to the rotor, but directly goes to the frame. In this process,

it is concluded that in a wide range of regulation, as a rule, the power on the motor shaft cannot be reduced.

When the rotation speed of the rotor decreases, the change in losses in one direction or the other does not allow for a decrease in the cooling air and the machine is always efficiently cooled.

ŞIXƏLİYEVA SƏADƏT YAŞAR qızı

TƏNZİM OLUNAN ASİNXRON MÜHƏRRİKİN KONSTRUKSİYASININ İŞLƏNMƏSİ VƏ TƏDQİQİ

XÜLASƏ

Dissertasiya texnoloji proseslərdə iştirak edən mexanizmlərin fırlanma sürətlərini dəqiq tənzimləyə bilən və yüksək energetik göstəricilərinə malik olan iki rotorlu asinxron mühərrikin konstruksiyasınının işlənib hazırlanmasına və tədqiqatına həsr edilmişdir.

Yeni konstruksiyalı rotor qısa qapanmış rotorlu asinxron mühərrik və onun fırlanma sürətinin tənzimlənməsinin prinsipinə əsaslanaraq ümumi anlayışa malikdir. Əsas işçi və köməkçi rotorun funksiyaları barədə tam məlumat verilmişdir və iş prinsipləri tam izah edilmişdir. Fırlanma sürətinin tənzimlənməsini nəzərdən keçirdikdə, kritik sürüşmə dəyişməsi stator dolağına verilən gərginliyə görə təhlil edilmişdir və dəyişən gərginliklər üçün sürət qrafikləri analiz edilmişdir.

Rotorun konstruksiyasının xüsusiyyətləri araşdırılmış və rotor dolağının ayrı-ayrı hissələrinin mühərrikin işinə təsiri izah edilmişdir. Yüksək müqavimətə malik qısa qapanmış halqanın qrafiki görünüşləri və onun maşının iş prosesinə təsiri verilmişdir.

Ümumi məsələlər sırasında işçi rotorun itkilərinin həcmi məsələləri nəzərdən keçirilmişdir. Eyni gücdə olan maşınlarla müqayisədə, bu mühərrikin rotor dolağının mis keçiricisindən olması maqnit dövrələrindəki itkilərin azalmasını və onun həcmini hava aralığından statora keçməsini təsdiqləyir.

İstilik mənbələri və maşında əmələ gələn itkilərin miqdarı haqqında, həmçinin soyutma sisteminin tətbiq istiqaməti haqqında tədqiqatlar aparılmışdır.

Yeni konstruksiya səmərəli bir soyutma sistemi ilə təmin edilmişdir: soyuducu hava ilə kütləvi axınının bir ventilyasiya sistemi hesabına təmin edilməsində istiliyin rotora deyil, birbaşa gövdəyə ötürülməsi üçün yüksək müqavimətli qısa qapanmış halqa quraşdırılmışdır. Bu prosesdən bir qayda olaraq o qənaətə gəlmək olar ki, geniş diapazon aralığında tənzimlənə bilən mühərrikin valındakı gücün azaldılması müşahidə olunmur.

Rotor sürəti azaldıqda, bu və ya digər istiqamətdə itkilərdəki dəyişikliklər soyuducu havanın azalmasına mane olmur və maşın həmişə effektiv şəkildə soyudulur.

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