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TWO ROTOR ASYNCHRONOUS ELECTRIC MOTOR WITH ROTATION FREQUENCY REGULATION

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Abstract- The article is devoted to the development and research of the design of two-rotor asynchronous motors which allow precise control of the rotation speed of the mechanisms involved in technological processes and have high energy characteristics. The new rotor design has a general understanding of the squirrel-cage induction motor and the principle of speed control. The functions of the working rotor and auxiliary rotor are explained. Among the general issues the issue of the volume of losses of the working rotor is considered. Compared to machines of the same power the copper conductor of the rotor of this motor which has a high conductivity in the magnetic circuits confirms the reduction in losses and the volume of their passage through the air gap into the stator. The design of the engine provides for an efficient ventilation system in the form of an auxiliary rotor which ensures the mass flow of cooling air. Thanks to the additional ventilation the main heat of the motor is not transferred to the stator but directly to the surface of the machine. At the same time, it is concluded that in a wide range of regulation the power on the motor shaft as a rule does not decrease. With a decrease in the rotor speed a change in losses in one direction or another does not allow reducing the consumption of cooling air and the machine is always efficiently cooled.

Keywords: Speed of Rotation, Regulation, Working Rotor, Active Resistance, Short Circuit Rotor, Groove Insulation, Cooling Air, Stator, Sliding, Losses.

1. INTRODUCTION

Regulation of the speed of rotation of the working body of the mechanisms used in the technological process in all areas of the national economy is the main condition. Examples of machines that require regulation are rolling mills paper making material handling agricultural textile and other machines. In all cases the regulation of the speed of rotation makes it possible to conveniently use production mechanisms create an optimal mode of their operation and reduce energy costs.

With progression of the electrical machines, it becomes hard to achieve economy of materials in given level of the energetic characteristics. The improvement of the electro technical characteristics of steel increasing of the filling coefficient of the groove with copper increasing the heat resistance of the insulation and rational choice of the active parts geometry have already been exhausted. In these conditions the cooling intensity demand is increasing. It is mainly related to the machine IP44 with parametrical regulation of the rotation frequency where at low rotation frequency the amount of energy losses is increasing several times. It is known that there are two main ways to control the speed of rotation of the working bodies of mechanisms: changing the parameters of the kinematic chain and changing the speed of the electric motor. The technical implementation of the first method is very complicated and unreliable [1].

When adjusting the speed of rotation of the mechanisms with the help of electric motors the adjustment is made regardless of the torque on the shaft and at the request of the working body. An analysis of the mechanical characteristics of motors shows that the frequency of their rotation may be due to a change in the parameters of the electrical circuit (resistance) or the parameters of the power source (voltage. frequency). If the speed control of the electric motor is carried out under the influence of the first factor (changes in the parameters of the circuit or power supply) then the change in torque causes a difference from the set value [3].

2. INDICATORS FOR EVALUATING THE CHARACTERISTICS OF THE SPEED OF ROTATION

2.1. Control Range Speed of Rotation

There are a number of indicators for assessing the characteristics of the speed of rotation. The most important of these is the control range which refers to the ratio of the maximum speed to the minimum speed in regulation. This is displayed in Equation (1):

$$D_{reg.} = \frac{\omega_{\max}}{\omega_{\min}} \tag{1}$$

Often the question arises of increasing the rotational speed which leads to an increase in D_{reg}. Of course, an increase in this range cannot be very wide. Increasing the upper limit of the rotational speed is usually limited by the mechanical strength of the armature or rotor of the electrical machine. The lower speed limit is legally limited by the most oscillatory state of the moment of static load on the motor shaft. Accuracy here refers to the ratio between the specified load torque and the actual speed. It is clear that the accuracy of speed control in the combination of the mechanism and the electric motor will be determined by the rigidity of the mechanical characteristics. Reducing the stiffness modulus will reduce the speed accuracy.

2.2. Mechanical Characteristic of the Rotational Speed

If the allowable limit for adjustment is not specified that is if the static load moment deviates from the possible value usually 0-(1.5÷2) M_s is taken as the zone for changing the static load moment, where, M_s is the reported value of the static load moment. In this case at the minimum value of the modulus of rigidity of the mechanical characteristic $\beta_{\min}$ the lower value of the rotational speed is determined by Equation (2):

$$\omega_{\min} = \frac{M_s}{\beta_{\min}} \tag{2}$$

2.3. The Smoothness of Control

One of the important indicators of the quality of speed control is the smoothness of control which is characterized by the difference between two successive speed values. The smaller this difference the smoother the adjustment will be. To assess this indicator, they often include the concept of a consumption adjustment coefficient which is understood as the ratio of two adjacent frequencies. This is displayed in Equation (3):

$$\gamma_{\varpi} = \frac{\omega_i}{\omega_{i-1}} \tag{3}$$

where, ω_i and ω_{i-1} are the value of i and i-1 stages of adjustment of the angular speeds of the engine corresponding to the case $\omega_i>\omega_{i-1}$. The smoothest regulation will be in the state $\gamma_{\varpi}\rightarrow 1$.

The smoothness of speed control depends on many factors including the technical performance of the method for changing the parameters of electrical circuits. In many cases it depends on the power of the electrical circuit the parameters of which are changed in order to regulate the speed. The speed control of electric motors of medium and high power by changing the resistance in the main circuit is carried out using contact devices. the number of which is limited. Under such conditions speed control is smooth so the number of switching devices increases with a decrease in the smoothness factor.

If the parameters of the electric circuit for speed control are changed under conditions of relatively low power switching devices are not needed. a sliding wire rheostat or a resistance with many wire protrusions can be used in which case the smoothness coefficient of the resistance correction will be equal to one.

In some cases, it is impossible in principle to change the rotational speed for example by changing the number of pole pairs in an asynchronous machine.

Adjustment of the rotational speed of a mechanism working with an electric motor is possible under mechanical load conditions at which the engine can be unlocked. Usually, the normal operation of the engine is considered when the magnitude of the currents in the electrical circuit of the engine does not exceed the rated value under continuous load. At the same time energy losses are left in the form of heat in the motor windings.

Thus, in order to determine the release torque in general. it is necessary to determine its value according to the nominal current of the main circuit at different values of the rotation frequency and thereby determine the dependence of $M_{bb}(\omega)$. However, this method should be refined to determine $M_{bb}(\omega)$. This is explained by the fact that in a self-cooled engine the flow of cooling air decreases when the frequency decreases from the nominal rotation frequency so heat removal worsens. In this regard it is necessary to reduce the losses in the motor that is to lower the currents in its windings. On the other hand, if the rotation frequency is raised above the nominal to the limit of mechanical strength tolerance the allowable value of the current may be higher than the nominal.

Thus, when determining the dependence of $M_{bb}(\omega)$ it is necessary to estimate the adjustment relative to the nominal value of the rotation frequency. In this sense the adjustment zone is divided above the main adjustment price and below the main adjustment zone. Accordingly, they also distinguish the methods of rotation frequency regulation.

2.4. Economic Indicators of the Regulation

When designing a variable frequency electric machine, it is also necessary to evaluate its economic indicators: initial costs - costs spent on the development of the engine and operating costs. The cost of developing an engine is compared to the cost of developing serial machines of the same power. In some cases, the mass and dimensions of the designed machine are also evaluated along with the cost comparison.

Operating costs as a rule are estimated by an indirect method mainly according to technical and energetic indicators: the useful work factor (U.W.F.) and the power factor in the regulation of the rotation frequency. Thus, during the working cycle, a number of rotation frequencies of the engine are determined for the average cycle. U.W.F. and the average value of the power factor is determined by the rule of integral evaluation of variable dimensions. U.W.F. considering that and the power factor is a function of the rotation frequency we can write as displayed in the Equations (4) and (5):

$$\eta_{average} = \frac{1}{\omega_{\max} - \omega_{\min}} \int_{\omega_{\min}}^{\omega_{\max}} \eta(\omega) d\omega \tag{4}$$

$$\cos\phi_{average} = \frac{1}{\omega_{\max} - \omega_{\min}} \int_{\omega_{\min}}^{\omega_{\max}} \cos\phi(\omega) d\omega \tag{5}$$

where, $\omega_{\max}$ and $\omega_{\min}$ are the maximum and minimum values of the rotation frequency respectively in the given regulation zone. To adjust the rotation frequency of engines of different power it is necessary to change the parameters of their electric circuits or power sources (voltage. frequency).

As a result, it is decided that in order to adjust rotation frequency it is necessary to change the parameters of the electric circuit of the motors (parametrically adjustable) and adjust the voltage of the power source; in alternating current motors as in the project adjustment can be made by changing the frequency of the power source. In the designed two-rotor asynchronous motor it is possible to adjust rotation frequency in a wide range using three methods shown [13].

3. COMPARATIVE ANALYSES

Since the middle of the 20th century and up to now many scientists have studied analyzed and searched for different ways to control the speed of squirrel cage induction motors of the 4A series and this process is constantly evolving. So, one of the factors affecting the efficiency the weight and mode of operation of many mechanisms is the regulation of the rotational speed.

In modern times these issues have been able to partially provide its effectiveness in scientific papers that consider the process of regulation. Because many of the disadvantages found in the course of research such as accuracy characteristics regulation range smoothness factor between torque and speed technical and economic indicators etc. difficulties in obtaining it at high prices complicate the working process and create to some extent obstacles in obtaining the necessary efficiency.

To clarify the hypotheses, consider the patent on the method of optimal regulation of a regulated induction motor the authors of which are D.B. Izosimov and L.N. Makarov. They regulated the rotor speed of an alternating current machine using a special voltage regulator. The technical result of the invention is to obtain the maximum electromagnetic torque by limiting the current and voltage of the power regulator which is involved in the regulation. In the applied method at low voltage values the value of torque M will decrease in proportion to the square of the voltage value U^2 supplying the stator winding. In this case it is necessary to reduce the static load or increase the voltage of the voltage regulator. In addition, other methods are presented: methods of motor rotation control by means of a direct current converter or inverter. An aspect of the named methods is that the regulation has a relatively high cost from an economic point of view and a certain limitation of its application from a technical point of view.

We can give an example of another patent the authors of which are M.M. Krasnoshapka, D.M. Krasnoshapka, N.I. Ustimenko. To achieve high torques and starting characteristics in this adjustable squirrel-cage induction motor the length of the rotor located in the stator package was increased by 20-30% by adding soft steel to the design by pressing it over the distance of the rotor elongation. This increases the active resistance of the rotor circuit the torque value does not decrease even at low voltages and the control range is extended. This design change faces the problem of increasing the size of the motor and eliminating heating temperatures in the rotor circuit. In this mode unless there is a perfect constant cooling system the life of the motor will be reduced.

This design change faces the challenge of increasing the size of the motor and eliminating heating temperatures in the rotor circuit. In this mode if there is no perfect permanent cooling system the life of the engine will be reduced. The creation of an engine with a double-rotor constant effective ventilation system can be considered as a solution to some problems in order to remove the heated temperature generated during adjustment from the passenger compartment of the machine. The creation of a twin-rotor engine with a constant effective cooling system can be seen as a solution to some of the problems in removing the heated temperature from the machine which is formed during rotation control. The presented asynchronous motor of a new design with an adjustable squirrel-cage rotor allows solving some of these adjustment problems and achieving efficient operating modes.

With the increasing of the regulation range (on machines with the regulating rotation frequency) the volume of the cooling air rapidly decreasing due to the reducing ventilation efficiency. These factors require to reduce the torque of the machines shafts which leads to increasing of the specific weight of the used materials. If engineering the ventilation for the low rotation frequency then at further increasing regulation range it will have very low cooling efficiency at low rotation frequency.

When producing the motors with this aim it should solve the problems of matching electromagnetic parameters with controlling devices parameters such as voltage stability of transducer and allowed limits of overload; regulating range; the choice of the engine capacity; defining additional loading; additional losses and torque and est. [1-4]. With other output parameters it should be provided acceptable torque and adequately acceptable heating temperature.

4. FORMULATION OF THE PROBLEMS

4.1. The Motor Construction

This article presents analytical studies of regulating asynchronous motors calculation of the permissible torque taking into account the heating mode some information about the design of the motor capable of regulating the speed in a wide range and analysis of the heating process taking into account heating conditions and temperature restrictions [5, 6].

For the achieving solution of the mentioned problems, it is suggested the following machine is the asynchronous motor enclosed type with parametric regulation of the rotation frequency. The motor is comprising enclosure stator main and additional rotors ventilator installed on the additional rotor (be noted that the main and additional rotors positioned coaxially). The additional rotor is simple short-circuited rotor designed for the ventilation system with magnetic conductor from the steel plates and the winding from the casted aluminum. The working rotor also is made from the electro technical steel plates with the winding from the casted copper with the different short-circuited rings are from the side of the additional rotor the rings is from copper from the opposite side the rings from the highly resistant metal.

For increasing the technical is economical parameters with keeping the large capacity of the torque at low rotation frequency i.e., for the increasing rage of the rotor frequency regulation it suggested the engine with design described in this article.

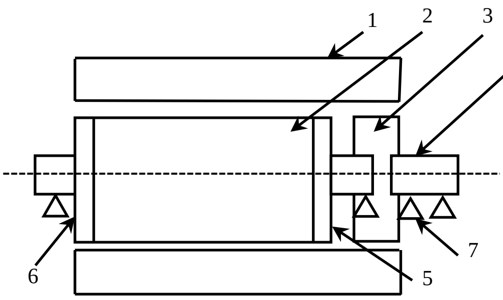

Figure 1. The motor construction scheme, 1- stator; 2- working rotor; 3- additional rotor; 4- shaft; 5- short circuit ring; 6- high resistance short circuit ring; 7- bearing

The design of the engine comprises the coaxially positioned working and additional rotors with the common stator of the ordinary asynchronous engine (Figure 1). The torque created by working rotor depends from the rotor frequency parameters of the ventilator from the number of the coils of the stator winding and the load current of the motor stator. All mentioned parameters and values needs be adapted in such way that in every mode of the motor running the actual frequency of the working rotor to be maximum close to its required frequency [7].

The working and additional rotors rotate independently. There is bonding bearing between the working and the additional rotors. The additional rotor fixed with the bearing box and the bearing built into cover of the external venting fan. The additional rotor like the rotor of ordinary asynchronous machines designed;

$$\frac{r_2'}{S} = \frac{r_{2m}' + r_{2sc}'}{S}$$

in such way that change of the voltage on the stator winding does not affect significantly rotor frequency it rotates the fan of internal circulation and external ventilation blowing fan which has normal cooling even at low rotation frequency of the working rotor [10-12].

A short-circuit mode is created with short-circuited loops since the loop is short-circuited provided that the mode is taken into account. A short-closed ring placed in the direction of the additional rotor is cast together with the copper winding. The other short-circuited ring is made of high-resistance material to create a mode that matches the engine's mode as Figure 2.

It is possible to adjust the resistance value by changing the design of this short-circuited loop and the cross-section of the wire. By changing the resistance value, it is possible to adjust the stability of the regulation zone. Depending on the value of the voltage applied to the stator winding the working rotor will rotate with a certain rotation frequency. The value of the voltage is changed to adjust the rotation frequency over a wide range and thus the critical slip will change in direct proportion to the active resistance of the rotor r_2'.

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

where, r_1 are x_1 active and inductive resistances of the stator loop; r_1' and x_2' are the active and reactive resistances of the rotor transformed into the stator winding.

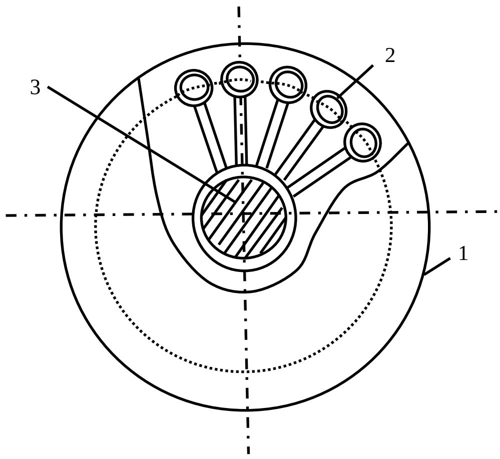

Figure 2. Location of high-resistance short circuit, 1- working rotor; 2- short closing ring; 3- working rotor shaft

Resistance r_2' consists of two summaries; the active resistance of the copper loop of the working rotor is r_{2m}' and the active resistance of the short-circuited ring is r_{2sc}'. Due to the active resistance the value of the critical slip - S increases by taking. By adding a large resistance to the rotor circuit this increase is taken into account by adding r'_{2sc} in the switching scheme of the machine into account the value of the maximum torque (Figure 3).

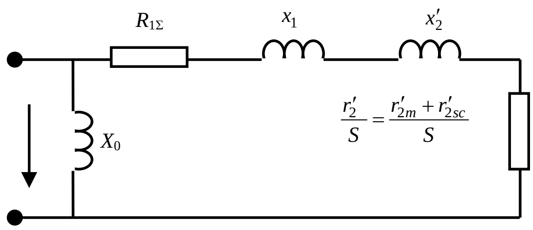

Figure 3. Replacement scheme of the machine

In Figure 3, $R_{1\Sigma}$ is the total active resistance of the stator winding phase and the VRT (voltage regulating thyristor) element, X_0 is the inductive resistance shown in the switching scheme is the influence resistance of the control system, x_1 is the inductive resistance of the stator loop, and x_2' is the reactive resistance of the rotor turned into the stator winding.

Depending on the magnitude of the voltage supplied to the stator winding the rotational speed of the working rotor can vary over a wide range. In this case the moment on the machine shaft will be determined depending on the temperature regime of the stator (magnetic circuit.

windings and winding insulation). In the additional rotor the process differs dramatically. Depending on the value of the voltage supplied to the stator winding the value of the critical slip will be the same as in a normal short-circuited rotor induction motor. The rotation frequency of the rotor will not differ from the rotation frequency of a normal asynchronous motor:

$S_n = 0.002 \div 0.05$

This process is important for the engine's ventilation system. In accordance with the low value of the supply voltage while the working rotor has a low rotational frequency the rotational frequency of the auxiliary rotor is very close to the synchronous speed. This ensures that the ventilation system is highly functional.

The designed asynchronous motor is created for automatically controlled technical structures control systems and other regulated transmission devices. To select the characteristics of the designed machine, there must be different values of the parameters so that the characteristics are obtained for any required speed. To do this, you need to change the active resistance of the rotor so that each resistance has its own characteristic [4].

Table 1. Starting characteristics in the case of an all-brass winding rotor

Cast copper rotor winding	Slip					
	1.0	0.8	0.5	0.2	0.1	0.15
Stator current $J_* \frac{J_1}{J_{1n}}$	5.66	5.59	5.21	4.01	2.74	3.48
M_*	1.92	1.50	1.82	2.45	2.22	2.49

Calculation of start-up characteristics in electric machines is performed based on generalized rules. Based on this calculation the characteristics were calculated for the all-copper structure in the rotor winding and for the resistance of five units of one short-circuit ring made of high-resistance metal-fexral (Table 1) in Figure 4. The reported values of the starting characteristics in the mode when one of the short-circuiting rings of the rotor winding is made of a ferromagnetic material are given in Table 2.

Table 2. Mechanical characteristics of the machine depending on the resistance of the short circuit ring $M_* = f(r_2')$

Short circuit resistance r_2'		Slip					Critical slip
		1.0	0.8	0.5	0.2	0.1	
1.68	M_*	2.0	1.75	1.2	0.51	0.27	0.6
3.51	M_*	2.25	2.05	1.48	0.62	0.35	0.8
5.31	M_*	2.5	2.23	1.70	0.75	0.45	1.0
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	-

Having calculated and derived the starting characteristics of the engine for several variants of active resistances of the electric circuit, it was determined that the presence of a copper winding of the rotor and the presence of one short circuit ring made of high-resistance material-fexral is an indicator of an improvement in the torque characteristic.

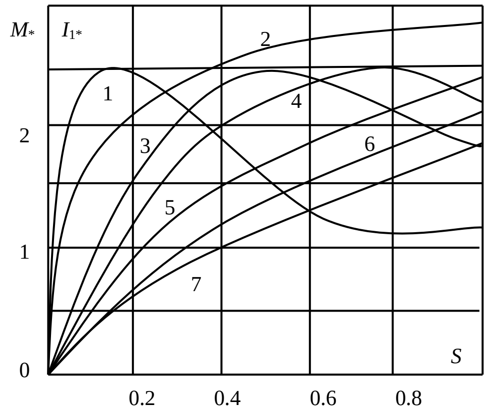

Figure 4. Starting characteristics of the designed motor, 1) stator current with a copper winding of the rotor; 2) moment characteristic with a copper winding of the rotor; 3-7) torque characteristics at various resistance values, when one short-circuiting ring of the rotor is made of high-resistance fexral

4.2. Relationships between Engine Warm-Up Process and Torque

In asynchronous machine IP44 type almost all loses $\sum \Delta P$ transmitting to atmosphere through the motor frame. The temperature on the surface of the frame is defining by these loses shown in the Equation (6) [14-16]:

$$\theta_f = \frac{\sum \Delta P}{S_{cool} a_f} \quad (6)$$

where, S_{cool} is the surface of the cooling frame; α_f is coefficient of the frame surface heat transferring; and θ_f is temperature of the frame surface [13].

The total losses in the machine ΔP consist of electrical losses in the winding of stator ΔP_1 and rotor ΔP_2. During regulation due to significant increasing of electrical losses the losses in the steel of stator can be ignored (when induction reduces, they are decreasing abruptly) and mechanical losses can be ignored (except the ventilation losses). With counting additional losses, the total losses in the machine:

$$\sum \Delta P = \Delta P_1 + \Delta P_{2w} + \Delta P_{2A} + \Delta P_{swr} + \Delta P_{add} + \Delta P_v$$

where, ΔP_1 is the electrical losses in the winding of the stator; ΔP_{2w} is the electrical losses in the working rotor; ΔP_{2A} is electrical losses in the additional rotor; ΔP_{swr} is losses in steel of working rotor; ΔP_{add} is total additional losses in machine; and ΔP_v is ventilation losses.

For evaluation of the heat mode of the motor the equation of total losses can be written the following way as in Equation (7):

$$\sum \Delta P = \Delta P_1 + \Delta P_2 + \Delta P_3 \quad (7)$$

where, $\sum \Delta P_2 = \Delta P_2 + \Delta P_{swr}$ is electrical and magnetic losses working rotor; and $\sum \Delta P_3 = \Delta P_{2A} + \Delta P_v$ is electrical losses of the additional rotor in ventilation.

The losses in the rotors (8), (9) due to defined value of the torques (M_w, M_A) and range of regulation.

$$\sum \Delta P = M_w S_{\max.w} \varpi_w \quad (8)$$

$$\sum \Delta P = M_A S_{\max.A} \varpi_A \quad (9)$$

where, $S_{max.w}$ and $S_{max.A}$ are the maximum sliding of the working and additional rotors relevantly; ω_w and ω_A are the angle frequency of rotating rotors; and M_w and M_A are torquing of the rotor shafts.

Usually, the temperature mode of the motor is limited by the allowable temperature of the stator winding depending from the applied insulation heat-resistance class. For the normal asynchronous motors in practice the temperature mode is defined by heating the surface of the frame θ_f. Its value for the normal motor does not exceed (40÷50) °C.

Heating of the stator winding in Equation (10):

$$\theta_{win} = \theta_f + \theta_s + \theta_i \tag{10}$$

where, the θ_f is the temperature on the surface of motor frame (1); θ_s is the drop of the temperature in the steel; and θ_i is the drop of the temperature in the insulation.

In some cases, during the heat calculation drop of the temperature in the stator steel can be ignored but during precise calculation then needs to calculate it as well because there are cases when that drop reaches the value (10–15) °C; drop of the temperature in insulation is usually within (20–30) °C.

Based on these analyses for the insulation with the heating resistance class is *F* at θ_{win}=100 °C we will have θ_f= (35–60) °C, but for the insulation with resistance class is *F* at θ_{win}=75 °C, θ_f=(30–40) °C [3].

Conducting experimental research on the motors enclosed types with the height of the rotation axis 132 and 160 mm showed that they have θ_f= (65–75) °C.

The torque is Equation (11):

$$M = \frac{\Delta P_2}{\Omega_1 S_{\max}} \tag{11}$$

In Equation (11) multiplying and dividing the torque by ∑ΔP. we obtain Equation (12):

$$M = \frac{\Delta P_2 S_{cool} \alpha_f \theta_f}{\Omega_1 (\Delta P_1 + \Delta P_2 + \Delta P_{add})} = \frac{S_{cool} \alpha_f \theta_f}{\Omega_1 S_{\max} (1 + \Delta P_1 / \Delta P + \Delta P_{add})} \tag{12}$$

If we consider ΔP_{add} in Equation (12) in the first approach we get Equation (13):

$$M = \frac{S_{cool} \alpha_f \theta_f}{\Omega_1 S_{\max} (1 + \Delta P_1 / \Delta P_2)} \tag{13}$$

The Equation (13) shows that with defined α_f, S_{cool}, θ_f, S_{max} by changing the ratio of loss between stator and rotor it is possible to significantly increase allowable value of load torque. On the ordinary motors for achieving high efficiency it is taken $\Delta P_1 \approx \Delta P_2$ sometimes $\Delta P_1 > \Delta P_2$ in case of the regulating motors the value of efficiency does not defining factor that is why it is possible and needs to change this ratio so that $\Delta P_1/\Delta P_2 < 1$.

The Equation (14) allows to calculate the torque with acceptable heat on parametrical regulating asynchronous motors enclosed types. When $\Delta P_1/\Delta P_2<1$ then it needs to greatly decrease the torque on motor shaft which decreases the techno-economical indications. Part of the losses ΔP_2 gets through the air gap into the stator pack and heating the winding insulation: for the normalizing the heat mode it is necessary to decrease the torque on the shaft.

5. SOLUTION OF THE PROBLEMS

In the studied model the heating process proceeds other way; for reducing the impact of the rotor temperature to the heat mode of stator it was created cooling channels through which the cooling air flow through the internal cavities of the working and additional rotors gives advantage to reduce significantly the impact of the rotor temperature to the stator winding. Just the acceptable insulation temperature of the stator winding is the main barrier which regulates the torque on the motor shaft [17].

Let study the heat flow of the accepted motor construction (it is considered that the heat flow gets through the steel of the stator pack). All types of the losses included in the Equation (7) becomes heat flow directed to the frame side where it is dissipating to atmosphere. On the picture 2 it is shown the heat flow pass. As the stator of the motor with parametric regulated motor is the element of the normal asynchronous engine the winding of the stator is overloading by heat flow which comes into the stator pack through the air gap increasing the winding temperature defined by the Equation (11). Due to the small gap between stator and rotor packs the stator exposes to the considerable heat $Q_{main\ air\ flow}$ (Figure 5a). Herewith the main portion of the rotor heat flow passes to stator pack through the air gap not significant portion are into the internal void $Q_{in\ cav.}$ which are transferring through the bearings to frame pass of this flow becomes difficult due to emitting of heat in the bearings. Heat flow $Q_{air.flow}$ is heating the winding wires and insulation as well as the stator iron.

Eventually the flows Q_1, Q_2 and Q_3 becomes the main heat load for the insulation of the stator winding. To avoid this, it is necessary to reduce the torque on the shaft of the machine that leads to increasing the overall dimensions and material consumption. Also, the range of the regulation is decreasing at the defined torque. In studied model some modifications (ventilation channels in both rotors rotor winding from copper magnetic conductor from the electro-technical iron) change the heat flows spreading (Figure 5b) which significantly improves working regime.

First creation of the ways for the heat flows through the internal cavities coaxial located rotors significantly reduces the temperature which restrain transfer of the heat power through the air gap to the stator. Second in the ordinary motor (Figure 5a) the large portion of the heat was passing into the stator. In the developed model (Figure 5b) the large portion of the heat is passing into the iron-frame through the ventilation channels in the rotor's cavities the small part of the heat is passing through the stator pack all of this increasing the range of the regulation.

Heating of all elements of this design is associated with power losses in the machine [7]. We can consider the followings: the volume of energy consumption for cooling is mechanical energy. The energy losses due to the movement of the cooling volume in the channels are divided into circulation losses and friction losses on rotating surfaces.

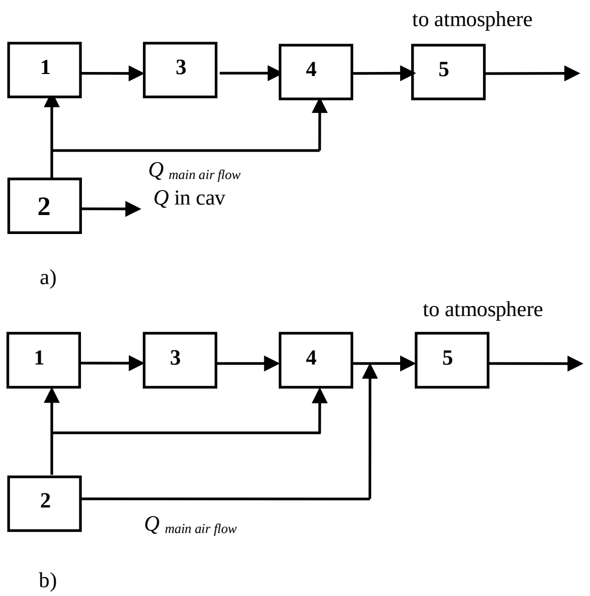

Figure 5. The heat scheme of ordinary serial asynchronous motor and the developed construction: a) ordinary motor; b) the motor with two coaxially located rotors and internal ventilation channels, 1- Stator winding; 2- working and additional rotor; 3- slot insulation; 4- stator core (stator iron); 5- iron-frame

The friction loss (in kilowatts) from the rotation of cylindrical surfaces is determined by the following Equation (14):

$$\Delta P_j = 57.3\left(\frac{n}{300}\right)^3 D^4 L \tag{14}$$

where, D is the diameters of the working and auxiliary rotors. L is the lengths of two rotors in sum meter; and n is rotational speed. rev./min. The losses due to the rotation of the lateral sides of the rotors are calculated with the following equation (15):

$$\Delta P_i = 2C_r \frac{\rho n^2 R^5}{2\cdot 0.88}10^{-4} \tag{15}$$

where R is the outer diameter of the rotors, ρ is air density and C_r is the coefficient of the moment of resistance which is calculated depending on the driving mode volume and geometrical dimensions of the machine.

If the engine being designed has a speed regulation in a wide range, then in this case the chosen ventilation system must fully meet the regime requirements. This means that with decreasing speed below the highest frequency ventilation system should be active. In commercial asynchronous motors when the rotational speed drops below asynchronous speed the activity of the ventilation system decreases sharply. This is due to air supply is strongly dependent on the rotational speed. For this reason, as the speed decreases the temperature increases and the load on the shaft must be reduced otherwise the temperature of the winding insulation will be higher than the permissible value which will lead to engine failure. This means that the engine utilization rate will decrease.

In the design of the engine this question is advantageous for economic reasons. The placement of an additional rotor in the stator zone greatly facilitates this issue; the rotational speed is regulated with adjusting of voltage applied to the stator winding. An additional rotor connected to both fans even at low voltages rotates at an asynchronous speed. Therefore, regardless of the main rotor speed ventilation system provides the required cooling medium with the cooled air volume. This means that even at low speeds the electrical machine is used at a high level. Economic efficiency in this case decreases therefore in a certain expenditure time capital and operating costs are taken into account.

6. CONCLUSIONS

The conducted analytical studies of asynchronous motors with parametrical regulating of current showed the following:

1. By removing the active resistance from the working rotor mass and leaving it in electrical scheme gives the opportunity to greatly decrease the heat flow getting through the stator winding insulation.
2. The studied design for the asynchronous motor with regulating rotation frequency gives opportunity to increase power and regulation range decreases the consumption materials in compare with the ordinary motors.
3. Creation of construction scheme of the heat flow gives opportunity to propose (imagine) the heat processes in asynchronous two rotors motors with parametrical regulation
4. The gained data from the study allows to define the approximate dependency between torque on the main shaft and the range of the regulation. Defining the volume of the losses in the rotors and passing some volume of the heat flow in stator requires the precise calculation on base of methods and laws of the heat transferring.
5. The developed construction of asynchronous motor allows to regulate the frequency of the working rotor in wide range by change of the voltage on the stator winding.
6. The additional rotor maintain heat regime especially at low frequency of working rotor. When the voltage decreases the frequency of the cooling fan does not change the cooling process normally continues.

NOMENCLATURES

Symbols / Parameters

D_{reg}: Regulation range
$\omega_{\max}$: Maximum rotation speed
$\omega_{\min}$: Minimum rotation speed
M_s: Static load moment
$B_{\min}$: Stiffness modulus of the mechanical characteristic
γ_{ϖ}: Smoothness correction factor
ω_i: Value of i a stage of adjustment of the angular speed of the engine
ω_{i-1}: Value of i-1 a stage of adjustment of the angular speed of the engine
$\eta_{average}$: Efficiency factor in the regulation of the rotation
$\cos\varphi_{average}$: Power factor in the regulation of the rotation
θ_f: The temperature on the surface of motor frame
S_{cool}: The surface of the cooling frame
α_f: Coefficient of the frame surface heat transferring

ΔP: The total losses in the machine
ΔP_1: Electrical losses in the winding of stator
ΔP_2: Electrical losses in the winding of rotors
ΔP_{2w}: Electrical losses in the winding of working rotor
ΔP_{2A}: Electrical losses in the additional rotor
ΔP_{add}: Total additional losses in the machine
ΔP_v: Ventilation losses
$S_{max.w}$: The maximum sliding of the working rotor relevantly
$S_{max.}$: The maximum sliding of the additional rotor relevantly
ω_w: The angle frequency of working rotor
ω_A: The angle frequency of additional rotor
M_w: Torques of the working rotor shaft
M_A: Torques of the additional rotor shaft
θ_s: The drop of the temperature in the steel
θ_i: The drop of the temperature in the insulation
Q: The heat flow
D: The diameters of the working and auxiliary rotors
L: The lengths of two rotors in sum meter
n: Rotational speed rev./min
ΔP_j: The friction loss (in kilowatts) from the rotation of cylindrical surfaces
ΔP_i: The losses due to the rotation of the lateral sides of the rotors
C_r: The coefficient of the moment of resistance
R: The outer diameter of the rotors
P: Air density

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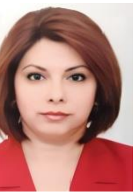
BIOGRAPHY



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