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Informational and Structural-Parametric Models of Inductions Micromotors

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Abstract: *Inductions motors play an important role in various areas of their application. Especially important among such engines are inductions micromotors. The breadth of use of inductions micromotors necessitates the construction of various models for such engines in order to determine the parameters of their design and operation characteristics. The article reviews the designs of existing inductions motors. An information and structural-parametric model for determining the design of inductions micromotors and their main characteristics are proposed. Calculations have been performed for one of the modifications of an inductions micromotor. The effectiveness of the proposed features modification an inductions micromotor is shown. The reliability and efficiency of the developed models for determining the design of the considered modification of an inductions micromotor is shown.*

Keywords: *Winding, Stator, Rotor, Frame, Information Model, Structural-Parametric Model, Inductions Micromotor.*

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I. Introduction

Any electric machine can be used both as a generator and as an electric motor. An electric machine can also be used to convert the electrical energy of one current kind (frequency, number of AC phases, DC voltage) to another current kind. Depending on the type of electrical installation current in which the electric machine is to operate, they are divided into DC and AC machines. Alternating current machines can be either single-phase or multi-phase. The most widely used are three-phase synchronous and inductions machines, as well as AC catheter machines, which allow economical regulation of the rotational speed over a wide range [1].

At the same time, today it is impossible to find an industry where frequency-regulated electric drives with driven inductions motors (IM) would not be used. Most production machines and mechanisms for general industrial use (fans, pumps, conveyors) require a relatively small range and low accuracy in speed control, relatively low speed.

Inductions motors are the most common type of electric motors. Inductions motors account for at least 80% of all electric motors manufactured by the industry. The total amount of electricity used to drive all drives with inductions motors is more than 50% of all consumed electricity [2]. The wide distribution of inductions motors is explained by the simplicity of their design, reliability in operation, good performance, low cost and ease of maintenance as an electrical machine. Inductions electric motors also have a relatively high efficiency (efficiency): at capacities of more than 1 kW, the efficiency is 0.7-0.95, nevertheless, in micro-motors, the efficiency is reduced to 0.2-0.65 [3, 4].

The need for inductions micromotors is increasing all the time (for example, up to six micromotors are used in a modern video camera). This necessitates the various models construction of such engines in order to determine the parameters of their design and characteristics for different operating conditions.

II. Materials and methods

2.1 Related work

The effective use of electrical energy is the research subject by many authors. Therefore, the structure, parameters and their evaluation, especially the control of IM, can be considered a very urgent task. In the identification process, the certain parameter evaluation of an inductions micromotor is transformed into a multidimensional optimization problem, where internal parameters are considered as solution variables. With this approach, the complexity of the optimization problem tends to create multimodal error surfaces, for which their cost functions are extremely difficult to minimize [5].

In [6] the existed parameters identification methods both online and offline are analyzed and compared, and the advantages and disadvantages of the various algorithms are listed it tables. A comprehensive identification method of adjustable model which makes the least square method as adaptive method of model reference is presented. The outlook of developing direction for parameters identification of asynchronous motor are put forward to.

The aims in [7] at providing a review of the major techniques used for the induction motor parameter estimation.

Automatic parameter identification of inverter-fed induction motors at standstill are presented in [8].

In [9] a steady-state model of a split-phase induction motor is investigated. Equivalent circuit parameters are estimated via a least-squares fit to experimental data and have been obtained through dc, locked rotor, and unloaded motor tests. Parameters were further refined using experimental data at rated load.

In [10] turns ratio has been replaced by a computed complex voltage ratio, based on an assumption that single-phase motor for parameter transformation can be represented as an ideal transformer. The equations for this complex quantity have been derived that provide an alternative to winding ratio test, which otherwise requires the tedium of a physical test on the motor. The performance variables like input current, power factor, and power consumed by the motor, obtained by the proposed technique, have been compared with those obtained using the conventional techniques as well as with the experimental observations obtained on three fan motors of different ratings.

2.2 Overview of inductions micromotors

Single-phase inductions micromotors are the most common type, they meet the requirements of most devices and apparatus electric drives, differing in low cost and noise level, high reliability, do not require care and do not contain moving contacts.

IM can be with one, two or three windings. In a single-winding motor there is no initial starting torque, and to start it you need to use, for example, a starting motor. In a two-winding motor, one of the windings, called the main winding, is directly connected to the supply network of Fig. 1, a [11]. To create a starting torque in another, auxiliary, winding, a current shifted in phase relative to the current in the main winding must flow. For this, in series with the auxiliary winding an additional resistor is included, which can be active, inductive or capacitive in nature. Three-winding three-phase IM can be used in single-phase power mode. In Fig. 1, b shows its inclusion in the "star" and "triangle" schemes in single-phase operation. Two of the three windings are directly connected to the supply network, and the third is connected to the supply voltage through the starting capacitor. To create the required starting torque in series with the capacitor, it is necessary to include a resistor whose resistance depends on the parameters of the motor windings [12].

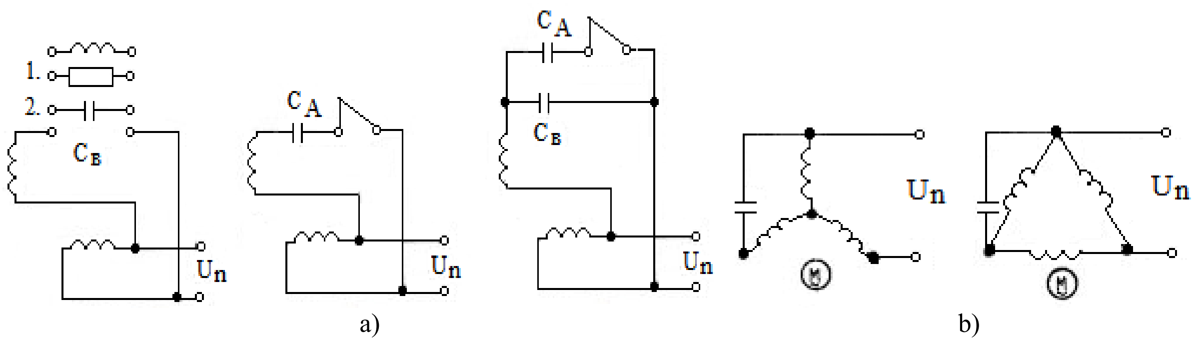

Fig. 1. Schemes for connecting windings

III. Results

3.1 Development of the inductions micromotors information model

Information model (INM) is an object model, represented in the form of information describing the parameters and variables of the object that are essential for the consideration, the connections between them, the inputs and outputs of the object, and allowing to model the possible states of the object by modifying the information on changes in input values [13]. But we can also consider different information model for IM.

To develop software for CAD systems, it is necessary to create an information model. It should be based on the data of the considered INM-devices for obtaining design solutions. All information about the IM design in the process of their automated synthesis is accumulated in the computer memory of the system in the arrays form and recorded in full accordance with the model.

The constructed object can be defined by combining in a certain structure of a certain elements set that have their own individual geometries.

There are several ways to present information about the geometry of the projected products. The most widely used for describing designs in the drawings form was the computer graphics method. So all the lines depicted in the drawing can be represented in the mathematical models form, therefore, the drawings models are considered as one of the modeling constructions ways of an induction motor.

The spatial model is the best for human perception and recognition. Therefore, in the processes of computer-aided design in order to increase efficiency, it is rational to represent the design in the set form of their quanta simulating the images of its constructive elements.

Information quanta correspond to the constructive elements of the projected products, and their aggregate, organized in a certain way, is the main part of the conditionally-constant CAD information.

In general, the design of an inductions motor can be represented by the following pair:

$$IM^{s} =< St_{i}, C > \tag{1}$$

where S – series IM with $s = 1..S$, S – number of series; St_{i} – set structural units of the IM design at $i = 1...I$, I – IM modification (1 – with increased starting torque, 2 – with increased slip, 3 – multi-speed, 4 – with phase rotor, 5 – with built-in electromagnetic brake, 6 – low noise, 7 – with squirrel-cage rotor); C – relations set between constructive elements.

We represent the information of an inductions motor in the information model form:

$$IM =< GI_{i}^{s}, PE_{i}^{s}, GCE_{i}^{s} > \tag{2}$$

where GI_{i}^{s} – general information of IM at $i = 1...I$, I – engine modification; S – IM series, $s = 1..S$, S – number of IM series;

PE_{i}^{s} – properties of IM elements at $i = 1...I$, I – engine modification; S – IM series, $s = 1..S$, S – number of IM series;

GCE_{i}^{s} – geometry (relative position) of the IM structural elements at $i = 1...I$, I – engine modification; S – IM series, $s = 1..S$, S – number of IM series.

Then the general information parameter GI_{i}^{s} can be described by such dependencies:

$$GI_{i}^{s} =< Cd_{i}^{s}, Dm_{i}^{s}, Ms_{i}^{s} > \tag{3}$$

where Cd_{i}^{s} – conventional designation of the IM modification at $i = 1...I$, I – engine modification; S – IM series, $s = 1..S$, S – number of IM series;

Dm_{i}^{s} – IM dimensions at $i = 1...I$, I – engine modification; S – IM series, $s = 1..S$, S – number of IM series;

Ms_{i}^{s} – mass at $i = 1...I$, I – engine modification; S – IM series, $s = 1..S$, S – number of IM series.

Properties of IM elements PE_{i}^{s} can be represented as:

$$PE_{i}^{s} =< Cde_{i}^{s}, Dme_{i}^{s} > \tag{4}$$

where Cde_{i}^{s} – conventional designation of IM elements (type) at $i = 1...I$, I – engine modification; S – IM series, $s = 1..S$, S – number of IM series;

Dme_i^s – sizes of IM elements at $i = 1..I$, I – engine modification; S – IM series, $s = 1..S$, S – number of IM series.

The geometry (mutual positioning) of the IM structural elements GCE_i^s is as follows:

$$GCE_i^s = < LD_i^s, ACD_i^s > \tag{5}$$

where LD_i^s – linear dimensions of IM elements at $i = 1..I$, I – engine modification; S – IM series, $s = 1..S$, S – number of IM series;

ACD_i^s – angular coordinating dimensions of the MI elements at I – engine modification; S – IM series, $s = 1..S$, S – number of IM series.

In Fig. 2 - Fig. 8 various IM modifications are presented in general form.

In Fig. 2 shows an IM with an increased starting torque [14].

Fig. 2. General view of IM with increased starting torque

Inductions motors with increased starting torque are intended for driving mechanisms with high loads during the start-up period [14].

In Fig. 3 is a general view of the IM with increased slip [14].

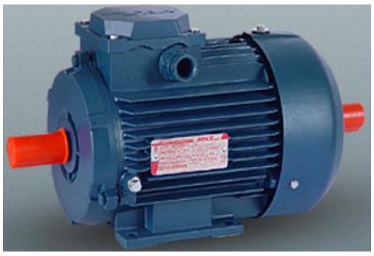

Fig. 3. General view of IM with increased slip

Inductions motors with increased slip are designed for driving mechanisms with a large inertia, as well as mechanisms operating in a short-time mode. Slip at the rated load of these engines is higher than that of the base ones, and the critical slip is about 40%, which is achieved by increasing the resistance of the rotor winding [14].

In Fig. 4 shows the general view of multi-rate IM [14].

Fig. 4. General view of multi-rate IM

Multi-speed inductions electric motors are designed for driving various mechanisms, during which the step speed control is required. Calculated for operation from a three-phase alternating current network [14].
In Fig. 5 shows a general view of an IM with a phase rotor [14].

Fig. 5. General view of an IM with a phase rotor

IM with a phase rotor is used for starting with a load on the shaft, since an increase in the resistance in the rotor circuit allows to increase the starting torque and reduce the starting currents [14].
In Fig. 6 is a general view of the IM with a built-in electromagnetic brake [14].

Fig. 6. General view of the IM with a built-in electromagnetic brake

IM with built-in electromagnetic brake are designed to drive mechanisms requiring a fixed stop for a regulated time after disconnection from the network [14].
In Fig. 7 is a general view of the low noise IM [14].

Fig. 7. General view of the low noise IM

IM low noise is used for freight elevators; are necessary for the drives of ship mechanisms [14].
In Fig. 8 shows a general view of the IM with a squirrel-cage rotor [14].

Fig. 8. General view of the IM with a squirrel-cage rotor

IM with squirrel-cage rotor is the most common electric motor used in industry. This engine can significantly reduce the energy consumption of equipment that it feeds, ensure a high level of its reliability, and increase the service life [14].

Thus, the information model of IM designs reflects the composition of the projected IM for the database development. The model contains information about the elements, their properties, mutual relations and relationships.

The problem of material selection in the IM design is one of the main, since it affects the durability, strength, wear resistance, etc., which affects the economic efficiency of the production preparation, therefore, the IM information model should take into account the choice of material.

When designing IM, one should take into account the workability and polishability of steel, the favorable properties of heat treatment; form reliability – wear and corrosion resistance; minimal repair and maintenance.

3.2 Development of the structural-parametric model of inductions motors

Accurate knowledge of the motor structure and parameters is a prerequisite for the next generation of an induction motor. The engine parameters are closely related to the most advanced control methods, such as direct torque control (DTC), model predictive control (MPC) and sensorless control. They affect the overall performance of the system to stimulate the research of new fault detection methods and extend to multiphase motors [7]. Incorrect estimated values cause inefficiency, which means loss of energy.

Therefore, on the basis of the information model, the structure-parametric model of IM is proposed:

$$\begin{aligned} PR_i^s =< & SH_i^s, BCO_i^s, BR_i^s, BCI_i^s, AGG_i^s, BSH_i^s, ID_i^s, \\ & BD_i^s, SC_i^s, RC_i^s, SW_i^s, RW_i^s, RBD_i^s, FA_i^s, CS_i^s > \end{aligned} \tag{6}$$

where SH_i^s – shaft; BCO_i^s – bearing cap outer; BR_i^s – bearing; BCI_i^s – bearing cap inner; AGG_i^s – air guide gun; BSH_i^s – bearing shield; ID_i^s – input device; BD_i^s – bed; SC_i^s – stator core; RC_i^s – rotor core; SW_i^s – stator winding; RW_i^s – winding of the rotor; RBD_i^s – rotor blades; FA_i^s – fan; CS_i^s – casing

To describe elements of the "shaft" type SH_i^s such a record:

$$SH_i^s = < Dem_i^s, Loc_i^s, Mat_i^s > \tag{7}$$

where Dem_i^s – dimensions elements of the “IM shaft” type; Loc_i^s – location "element"; Mat_i^s – shaft material.

Elements of the "bearing cover outer" type BCO_i^s will be described as:

$$BCO_i^s = < Dem_i^s, Loc_i^s, Mat_i^s > \tag{8}$$

where Dem_i^s – dimensions elements of the "bearing cover outer" type; Loc_i^s – location «element»; Mat_i^s – material elements of the "bearing cover outer" type.

Elements of the "bearing" type BR_i^s contains such characteristics:

$$BR_i^s = < Dem_i^s, Loc_i^s, Mat_i^s > \tag{9}$$

where Dem_i^s – dimensions elements of the "bearing" type; Loc_i^s – location «element»; Mat_i^s – material elements of the "bearing" type.

Elements of the "bearing cap inner" BCI_i^s can be expressed in the form:

$$BCI_i^s = < Dem_i^s, Loc_i^s, Mat_i^s > \tag{10}$$

where Dem_i^s – dimensions elements of the "bearing cap inner" type; Loc_i^s – location «element»; Mat_i^s – material elements of the "bearing cap inner" type.

Elements of the "air guide guard" type AGG_i^s includes the following components:

$$AGG_i^s = < Dem_i^s, Loc_i^s, Mat_i^s > \tag{11}$$

where Dem_i^s – dimensions elements of the "air guide guard" type; Loc_i^s – location «element»; Mat_i^s – material elements of the "air guide guard" type.

For description elements of the "bearing shield" type BSH_i^s such a record:

$$BSH_i^s = < Dem_i^s, Loc_i^s, Mat_i^s > \tag{12}$$

where Dem_i^s – dimensions elements of the "bearing shield" type; Loc_i^s – location «element»; Mat_i^s – material elements of the "bearing shield" type.

Elements of the "input device" type ID_i^s describe as:

$$ID_i^s = < Dem_i^s, Loc_i^s, Mat_i^s > \tag{13}$$

where Dem_i^s – dimensions elements of the "input device" type; Loc_i^s – location «element»; Mat_i^s – material elements of the "input device".

Elements of the "bed" type BD_i^s contains such characteristics:

$$BD_i^s = < Dem_i^s, Loc_i^s, Mat_i^s > \tag{14}$$

where Dem_i^s – dimensions elements of the "bed" type; Loc_i^s – location «element»; Mat_i^s – material elements of the "bed" type.

Elements of the "stator core" type SC_i^s can be expressed in the form:

$$SC_i^s = < Dem_i^s, Loc_i^s, Mat_i^s > \tag{15}$$

where Dem_i^s – dimensions elements of the "stator core" type; Loc_i^s – location «element»; Mat_i^s – material elements of the "stator core" type.

Elements of the "rotor core" type RC_i^s contains such characteristics:

$$RC_i^s = < Dem_i^s, Loc_i^s, Mat_i^s > \tag{16}$$

where Dem_i^s – dimensions elements of the "rotor core" type; Loc_i^s – location «element»; Mat_i^s – material elements of the "rotor core" type.

Elements of the "stator winding" type SW_i^s contains such characteristics:

$$SW_i^s = < Dem_i^s, Loc_i^s, Mat_i^s > \quad (17)$$

where Dem_i^s – dimensions размеры elements of the "stator winding" type; Loc_i^s – location «element»; Mat_i^s – material elements of the "stator winding" type.

Elements of the "rotor winding" type RW_i^s describe as:

$$RW_i^s = < Dem_i^s, Loc_i^s, Mat_i^s > \quad (18)$$

where Dem_i^s – dimensions elements of the "rotor winding" type; Loc_i^s – location «element»; Mat_i^s – material elements of the "rotor winding" type.

Elements of the "rotor blades" type RBD_i^s describe as:

$$RBD_i^s = < Dem_i^s, Loc_i^s, Mat_i^s > \quad (19)$$

where Dem_i^s – dimensions elements of the "rotor blades" type; Loc_i^s – location «element»; Mat_i^s – material elements of the "rotor blades" type.

Elements of the "fan" type FA_i^s can be expressed in the form:

$$FA_i^s = < Dem_i^s, Loc_i^s, Mat_i^s > \quad (20)$$

where Dem_i^s – dimensions elements of the "fan" type; Loc_i^s – location «element»; Mat_i^s – material elements of the "fan" type.

For description elements of the "casing" type CS_i^s such a record:

$$CS_i^s = < Dem_i^s, Loc_i^s, Mat_i^s > \quad (21)$$

where Dem_i^s – dimensions elements of the "casing" type; Loc_i^s – location «element»; Mat_i^s – material elements of the "casing" type.

IV. Discussion of simulation results

We will investigate some parameters of the information model. Below are the calculations of one of the modifications of an inductions micromotor – a three-phase IM with a squirrel-cage rotor. As the main parameters for the calculations were selected: power $P_{2n} = 0.18$ kW; = 1500 rpm, n_1 = 220/380 V, performance in accordance with the environmental protection method IP44. Other characteristics in accordance with the data of a similar serial engine are given in Table-1 and Table-2 [2].

Table 1 The data of the engine 4A series

IM size	P_{2nom}, kW	I_n, A	Electromagnetic loads			Energy indicators	
			δ, T	A, A / m	J, A/mm^2	η	cos ϕ
Synchronous speed of rotation 1500 rpm							
4AA50A4U3	0.06	0.303	0.64	13600	4.5	50.0	0.60
4AA50V4U3	0.09	0.413	0.68	15200	4.9	55.0	0.60
4AA56A4U3	0.12	0.437	0.71	14600	6.2	63.0	0.66
4AA56V4U3	0.18	0.666	0.75	16700	6.9	64.0	0.64

Table 2 The parameters of the engine 4A series

IM size	P_{2nom}, kW	Parameters of the replacement circuit in nominal mode, Ohm				
		X_{12}	R_1	X_1	R_2	X_2
4AA50A4U3	0.06	871.29	103.19	109.64	122.55	94.70
4AA50V4U3	0.09	639.23	61.88	76.16	87.09	70.50
4AA56A4U3	0.12	604.12	84.85	41.01	65.65	65.65
4AA56V4U3	0.18	428.43	56.84	27.92	46.23	49.12

We calculate the number of stator winding poles pairs [2]:

$$P = \frac{60 \times f_1}{n_1} = \frac{60 \times 50}{1500} = 2, \tag{22}$$

where f_1 – cyclic change rate of the stator magnetic flux is called the synchronous motor speed (the value is taken from Table-1).

n_1 – frequency of the AC mains (standard frequency 50 Hz).

The main dimensions can be selected from Table-3 for the corresponding power we find: outer diameter of the stator $D = 89mm$, height of rotation axis $h = 56mm$.

Table 3 Designation of engine values

P_2, kW	0.06 – 0.12	0.12 – 0.25	0.25 – 0.55	0.55 – 1.1	1.1 – 2.2
$\frac{h, mm}{D, mm}$	$\frac{50}{81}, \frac{56}{89}$	$\frac{56}{89}, \frac{63}{100}$	$\frac{63}{100}, \frac{71}{116}$	$\frac{71}{116}, \frac{80}{131}$	$\frac{80}{131}, \frac{90}{149}, \frac{100}{168}$

Based on the data from Table-3, a plot of the power versus the main engine sizes is plotted, the results are shown in Fig. 9.

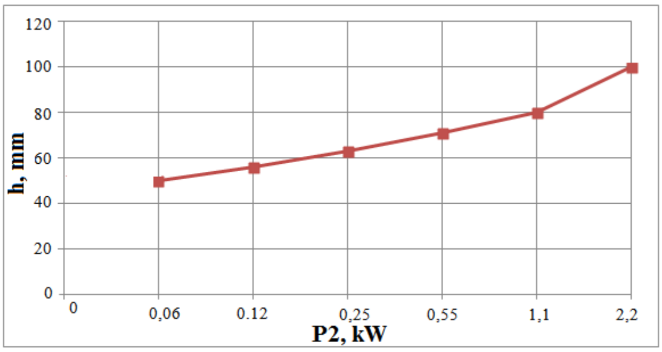

Fig. 9. Graph of power versus main engine sizes

Analyzing the constructed graph of the power dependence and the main dimensions of the engine, we can draw the following conclusion: depending on what the height of the rotation axis and the outer diameter of the stator depends on the engine power, in fact, as the stator diameter increases and the height of the rotation increases axis,

The internal stator diameter, for example, of an inductions micromotor with a squirrel-cage rotor is [2]:

$$D = K \times D_a = 0{,}62 \times 0{,}089 = 55 \times 10^{-3}, \tag{23}$$

where K – characterizes the ratio of internal and external diameters of the inductions micromotor stators cores of 4A series for different pole numbers; equal to 0.62 (the number of winding pole pairs 2 to 2 phases), according to Table-4;

D_a – outer stator diameter.

Table 4 The value of the K parameters in the engines of the 4A series at different pole numbers

2p	2	4	6	8÷12
K	0.57÷0.59	0.6÷0.65	0.7÷0.72	0.74÷0.77

The pole division of the IM [15]:

$$\tau = \frac{\pi D}{2p} = \frac{3{,}14 \times 55 \times 10^{-3}}{4} = 43{,}2 \times 10^{-3}. \tag{24}$$

Coefficient K_E – ratio of the stator winding electromotive force to the rated voltage is [2]:

$$K_E = \frac{X_{12}}{\sqrt{R_1^2 + (X_1 + X_{12})^2}} = \frac{429{,}4}{\sqrt{(56{,}8^2 + (27{,}9 + 429{,}4)^2)}} = 0{,}94, \tag{25}$$

where R_1, X_1, X_{12} – parameters of the substitution scheme in the nominal mode. Values are selected according to Table-2.

Calculate the calculated power according to the formula [2]:

$$P' = P_{2n} \times \frac{K_E}{\eta \times \cos\phi} = \frac{180 \times 0{,}94}{0{,}64 \times 0{,}64} = 413{,}1, \tag{26}$$

where $\cos \phi$ – value of the power factor is determined from Table-1;
η – value of the efficiency coefficient is determined from Table-1.

On the basis of the above calculations, a plot of the power versus the active resistance plotted R_1 in Fig. 10.

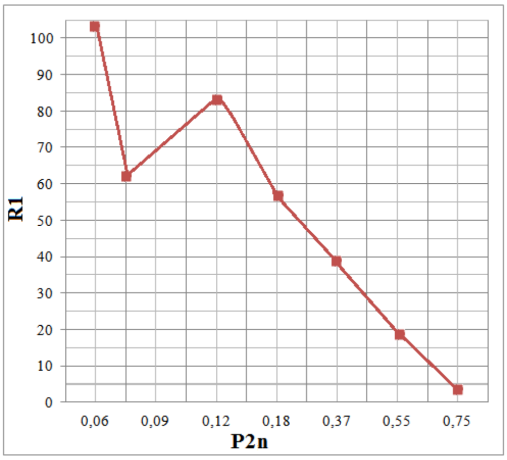

Fig. 10. Graph of power and active resistance R_1

Analyzing the constructed graph of the power dependence and the active resistance, we can draw the following conclusion: since the resistance R_1 in comparison with the inductive resistance is not equal, the influence of the active resistance will be greater when the engine has a lower power.

The developed information model includes the basic elements of inductions motors and the interrelations between them. The model became a prerequisite for a more detailed formalization of the engine design, presented in the form of a structurally-parametric model, which differs from the existing ones in that the model takes into account the series, the modification of elements and their location.

V. Conclusion

The structure of existing inductions engines is reviewed, engine modifications are analyzed. The questions of the spheres of application of engines are considered. On the basis of the analysis, the main components of inductions motors and their parametric features were determined, which subsequently became a prerequisite for the development of an information model on the basis of which the structure-parametric model of the IM was proposed.

The proposed structural-parametric model allows to determine the main design parameters of induction motors of their characteristics.

The proposed models can be used as a basis for developing a mathematical model in the process of creating a module for the automated design of inductions motors.

On the basis of the selected numerical values of the parameters of the inductions motor, calculations are made for some parameters of the model, as a result, dependence graphs of the IMs output parameters studied, affecting the operating costs and the efficiency of their operation are constructed.

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