Design of a pole changing winding for asynchronous machines drived on conveyors using the ANSYS Maxwell

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Abstract. The article considers the issues of increasing energy efficiency by using multi-speed motors, and also considers the problems of creating pole-changing windings. The procedure for constructing a new two-layer three-phase pole-changing winding with a pole ratio of 4/6, made in 36 stator slots on the basis of the basic switching scheme YYY/YYY, is presented. Based on the results of the analysis of the electromagnetic properties, the optimal winding pitch was selected. An experimental motor with a new pole-changing winding was created on the basis of a magnetic circuit of a serial asynchronous machine of the 4A132M4 type. The analysis of the properties of the electric motor was carried out using the ANSYS/Maxwell program. The results of experimental tests of a new two-speed motor in static and dynamic modes are also presented.

1 Introduction

Today, in the global mining industry, it is important to increase the energy efficiency of conveyor belts and use electricity economically. In this regard, much attention is paid, including optimal control of asynchronous motors of belt conveyor transport, rationing of electricity consumption, the search for combined methods of transporting minerals from deep horizons of open deposits and improving the reliability of conveyor equipment [1].

In the global mining industry, asynchronous motors with short-circuited rotors are usually used for electric drives of belt conveyors up to 3000 meters long and with a power of up to 100 kW. Simple design and low cost the advantage of such electric drives is the high starting torque and the associated appearance of large traction forces, as well as increased belt slippage, their disadvantage. There is a need to regulate the speed of the conveyor when the load current excavated in mines and mine workings increases or decreases [2].

In world practice, there are several methods of regulating the rotational speed of asynchronous motors, which include an asynchronous ventilated cascade, a thyristor frequency controller, and two-speed asynchronous motors are widely used.

The number of poles in the stator does not correspond to the additional change in energy provided in multi-speed electric drives based on asynchronous motors, in which there is a variable block, and is the only adjustment method in which additional waste is not spent on sliding, as a result of which their useful operating coefficient can be high

ANSOFT Maxwell is one of the leading electromagnetic field modeling software and is used to create and research projects of two-and three-dimensional models of electric motors, transformers, as well as various electrical and electromechanical devices [2]. The Maxwell program is based on the method of finite elements (Finite Element Method - FEM) and calculates static, electromagnetic and electric field harmonics, as well as, moreover, transient processes with very high accuracy [3]. With this in mind, instead of real experiments, it is possible to use computer models that are cost-effective.

Rotational Machine Expert (RMxprt) - it is a program that speeds up the processes of design and optimization of electrical machines. The calculation of the working characteristics of RMxprt electric machines uses classical analytical theories and equivalent methods of magnetic circuits. The following starting data of the electric motor are entered into the program: the type of windings and the connection scheme, the characteristics of the stator and rotor materials, geometric parameters, power supply, load, etc.k. Thus, this software tool allows you to significantly speed up the process of manufacturing an electric machine with a standard configuration [3]. As an object of study, let's consider an asynchronous electric motor with a short-circuit rotor of type 4A132M4. Figure 1 shows the basic dimensions of the asynchronous electric motor 4A132M4 using the Ansys Maxwell RMxprt software module.

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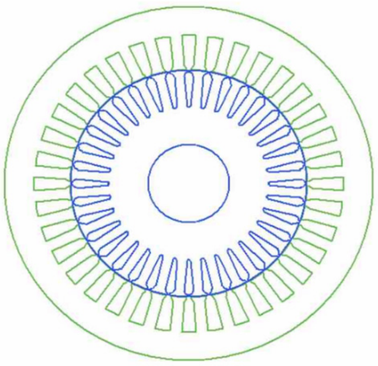

$D_{ext} = 225\ mm$
$D_{in} = 145\ mm$
$l_{st} = 180\ mm$
$Z_1 = 36$
$Z_2 = 34$
$D_{ext} = 144{,}2\ mm$
$D_{in} = 50\ mm$

Fig.1. The main dimensions of the electric motor 4A132M4

2 Calculation of the winding factor for a variable number of poles

The number of Poles is considered to be variable winding special chulgam, and the winding step will be uniform for both polarization sides. The only step taken from a technological point of view may be reduced for one pole and extended for the other. The listed factors significantly affect the value of the winding factor.

The value of the winding factor depends on the specifics of the winding scheme. The value of the first harmonic coefficient (n=1) is slightly less than unity, which leads to a slight decrease in the first harmonic of EDF (MDF). Higher harmonics (n = 5, 7, 11, 13, etc.) have a winding factor value much less than unity and its value is close to zero, as a result of which high EDF harmonics (MDF) are significantly reduced [4-15, 16].

The winding factor can be calculated separately for each harmonic using the generalized method [17-20] and the matrix method.

The use of the structural matrix of three–phase winding makes it possible to study winding EDF using the method of matrix algebra and determine the winding factor for any ν-harmonics. For the study of alternating current emission EDF by The Matrix method, the multiphase winding can be written in the following form by the α-ordered harmonic k digital phase EDF vector [4]:

$$\dot{E}_{\phi k\nu} = E_{\phi k} \cdot e^{j\varphi_{k\nu}} \tag{1}$$

here, the $E_{\phi k}$ -EDF vector module; $\varphi_{k\nu} - \dot{E}_{\phi k\nu}$ is the angle of rotation of the vector relative to the positive horizontal axis.

For ν -order harmonics, if the unit vectors EDF are brought to the matrix $[\dot{e}_z]_\nu$, they are written in the following form

$$[\dot{e}_z]_\nu = \begin{array}{c} 1 \\ 2 \\ 3 \\ .. \\ i \\ .. \\ z \end{array} \begin{bmatrix} \cos\nu 0 & \sin\nu 0 \\ \cos\nu\gamma & \sin\nu\gamma \\ \cos\nu 2\gamma & \sin\nu 2\gamma \\ \dots\dots & \dots\dots \\ \cos\nu(i-1)\gamma & \sin\nu(i-1)\gamma \\ \dots\dots & \dots\dots \\ \cos\nu(z-1)\gamma & \sin\nu(z-1)\gamma \end{bmatrix} \cdot \begin{bmatrix} 1 \\ j \end{bmatrix} = [\dot{e}'_z]_\nu + j[\dot{e}''_z]_\nu \tag{2}$$

here, $\dot{e}'_{z\nu}=\cos\ \nu(i-1)\gamma$ and $\dot{e}'_{z\nu}=\sin\ \nu(i-1)\gamma - [\dot{e}'_z]_\nu$ and $[\dot{e}''_z]_\nu$ matrix *i*–the number of elements, the number of slot matrix the number to the left ($i = 1...z$) recorded.

the ν-ordered harmonic can be written in the form of the following matrix expression when determining the *k*-digit $E_{\phi k\nu}$ phase EDF and its winding factor

$$\left. \begin{aligned} \dot{E}_{\phi k\nu} &= [C_\phi]_k^{\mathrm{T}} \cdot [\dot{e}_z]_\nu \\ E_{\phi k\nu} &= \sqrt{([C_\phi]_k^{\mathrm{T}} \cdot [\dot{e}'_z]_\nu)^2 + ([C_\phi]_k^{\mathrm{T}} \cdot [\dot{e}''_z]_\nu)^2} \\ tg\varphi &= \frac{[C_\phi]_k^{\mathrm{T}} \cdot [\dot{e}''_z]_\nu}{[C_\phi]_k^{\mathrm{T}} \cdot [\dot{e}'_z]_\nu} \\ k_{win.\nu} &= \frac{E_{\phi k\nu}}{N} \end{aligned} \right\} \tag{3}$$

where, $[C_\phi]^{\mathrm{T}}_k$ – k is the transponized matrix of the digital phase, N – k is the number of digital phase conductors, equal to the modulus sum of the elements of this $[C_\phi]_k$ phase Matrix.

The number of poles based on the basic "YYY/YYY" circuit with 36 equal stator slots and a pole ratio of 2:3 in the circuit is variable, with a pitch of y=6 for the pole side 2p=4, in the MDF form, except for the first harmonic, 2nd, 5th, 7th, 8th, 10th, 11th, 13th, 14th, 16th, 17th harmonics are present and their amplitude is 15.1%, 0.4 %, 0.6%, 0. 3%, 0.2%, 0.4%, 0.2%, 0.2%, 1.9%, 4.5%.

In addition to the first harmonic, there are 2nd, 7th, 11th, 14th, 16th, and 17th harmonics in the form of MDF when the winding step is y=7, and their amplitude is 7.9% as a percentage of the total harmonics, taking into account the winding factor, respectively. 0.4%, 0.3%, 0.3%, 1%, 5%.

In addition to the first harmonic, there are 2nd, 5th, 7th, 8th, 10th, 11th, 13th, 14th, 16th, 17th harmonics in the form of MDF with a winding step u=8, and their amplitude is taken into account. by winding factor 2.2%, 0.2%, 0.1%, 0.4%, 0.3%, 0.1%, 0.1%, 0.3%, 1.9 as a percentage of the amount harmonics respectively % is 5.4%.

Except for the first harmonica in the form of MDF when 2p=6 pole side of this winding is the winding step y=6 5-, 7-, 8-, 11-, 13-, 17-there are Harmonics, the amplitude of which, when taking into account the winding factor, is in the percentage score relative to the general harmonic, respectively 1,2%, 0,9%, 7,6%, 6,4%, 0,4% makes up the.

With the exception of the first harmonica in the form of a MDF, when the winding step is y=8 2-, 5-, 7-, 8-, 10-, 11-, 13-, 14-, 16-, 17- there are harmonics whose amplitude, when taking into account the winding factor, is in percentage the score relative to the common harmonic, respectively 9,6%, 1%, 0,7%, 0,8%, 1,9%, 6,5%, 5,5%, 1,4%, 0,4%, 0,3% makes up.

The winding MDF curve forms a stepped curve around the circumference of the stator, the magnitude of each step in the wedge is equal to the full current of the wedge, and its direction changes in the direction of the current.

By allowing you to determine the MDF for any point of the circle through the myuk integral curve and find its maximum value, you can distribute them along a harmonic line using well-known graphical methods and determine the amplitudes of the MDF harmonics [5].

It is very convenient to construct the Georges diagram for three-phase *m*- and *2m*-zone circuits using the triangular mesh tool, because the currents for the *2m*-zone consist of six-beam symmetrical stars with a turning angle between them of 60°. Their geometric summation can be performed on a triangular grid, the sides of which describe the spatial zone current vectors, and the value is conditionally assumed to be equal to one [21-27, 3, 2].

The Georges diagram allows to study the circuit composition of multi-phase electric machines. If the Georges diagram is symmetric about the axis of the center of gravity, then the negative half-wave of the curve of the MDF should repeat the positive half-wave, then the MDF will consist of only odd harmonic constituents, when the Georges diagram is symmetric, even harmonic constituents will also be present.

The Georges diagram allows us to quantify the level of composition of high harmonics on the MDF curve.

Differential Scattering Factor — is an electromagnetic parameter that characterizes the windings of AC electrical machines. The composition of various harmonics on the MDF curve can be estimated using the differential scattering coefficient.

Figure 2 shows a diagram of Gyorges when the number of stator poses is 36 and the stride step is y=7. The differential scattering factor for this winding step is $2p_1=4$ for the side $\sigma0=4.6\%$, $2p_2=6$ for the side - $\sigma_0=5.4\%$.

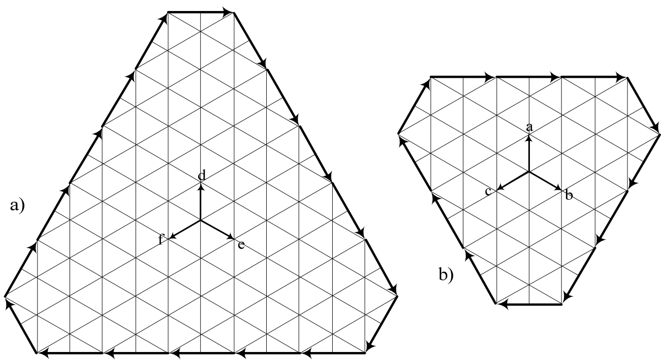

Fig.2. Georges diagram according to the YYY/YYY scheme with Z = 36 and y = 7: a) for $2p_1=4$ sides
b) for $2p_2=6$ sides

The calculation of the winding factor for each harmonic was performed in three steps of the winding. The values of the coefficient of variation for each harmonic are presented in Table 1

Table.1. Winding factor values

Z		*36*					
BC		*YYY/YYY*					
p		*p=for 2 sides*			*p=for 3 sides*		
y		*6*	*7*	*8*	*6*	*7*	*8*
Number of harmonics	1	0.801	0.87	0.911	0.837	0.808	0.724
	2	0.623	0.46	0.246	0.000	0.217	0.375
	3	0.000	0.21	0.375	0.000	0.000	0.000
	4	0.115	0.131	0.086	0.000	0.217	0.217
	5	0.097	0.019	0.072	0.224	0.058	0.194
	6	0.000	0.217	0.217	0.000	0.000	0.000
	7	0.227	0.201	0.09	0.224	0.058	0.194
	8	0.141	0.056	0.161	0.000	0.217	0.217
	9	0.000	0.000	0.000	0.000	0.000	0.000
	10	0.141	0.056	0.161	0.000	0.217	0.375
	11	0.227	0.201	0.09	0.837	0.808	0.724
	12	0.000	0.217	0.217	0.000	0.000	0.000
	13	0.097	0.019	0.072	0.837	0.808	0.724
	14	0.115	0.131	0.086	0.000	0.217	0.375
	15	0.000	0.217	0.375	0.000	0.000	0.000
	16	0.623	0.463	0.246	0.000	0.217	0.217
	17	0.801	0.87	0.911	0.224	0.058	0.194

3 Experimental studies of the working and mechanical properties of a two-speed electric motor

As a mechanical (working) characteristic of an asynchronous motor, in a narrow sense it is understood that the speed of rotation or slip depends on the given power, and in a broad sense a number of other values important for operation, that is, such parameters as input power, current, useful working coefficient and power coefficient, are understood at the invariant value of the given voltage and [5, 6].

Experimental studies of the new 4A132M4/6 engine show that $p_1=2$ on the side $P_2=9$ kW, $\eta=87\%$, $\cos\varphi=0{,}87$, $I_1=18$ A, M=58 nM, $p_2=3$ on the side $P_2=6$ kW, $\eta=85\%$, $\cos\varphi=0.51$, $I_1=20$ A, M=58 nM.

4 Conclusion

Based on the analysis of the results of the experimental studies presented above, it can be concluded that the number of Poles of a new type allows the introduction of a variable-flow-based two-speed motor instead of the single-speed motors available in the transport mechanisms of cargo transportation.

A study of experimental studies of working characteristics of new motors with variable two-speed poles showed that the energy performance of these motors fully corresponds to the required values.

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