International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 17, No. 1, March 2026, pp. 195~210
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v17.i1.pp195-210

Improving the energy efficiency of two-speed motors through the use of new pole-switched windings

Zhanat Issabekov[1], Dauletbek Rismukhamedov[2], Khusniddin Shamsutdionov[3], Shakhobiddin Husanov[2], Sabit Rismukhamedov[4], Bibigul Issabekova[1], Assemgul Zhantlessova[5]
[1]Department of Automation and Control, Faculty of Energy, Toraighyrov University, Pavlodar, Kazakhstan
[2]Department of Power Engineering and Mechanical Engineering, Faculty of Energy, Almalyk branch of Islam Karimov Tashkent State Technical University, Almalyk, Uzbekistan
[3]Department of Electric Power Stations, Networks and Systems, Faculty of Energy, Islam Karimov Tashkent State Technical University, Tashkent, Uzbekistan
[4]Department of Electrical Engineering, Faculty of Energy, Islam Karimov Tashkent State Technical University, Tashkent, Uzbekistan
[5]Department of Operation of Electrical Equipment, Faculty of Energy, S.Seifullin Kazakh Agro Technical Research University, Astana, Kazakhstan

Article Info

Article history:

Received Jun 26, 2025
Revised Jan 30, 2026
Accepted Feb 15, 2026

Keywords:

Basic scheme
Groove
Layer
Magnetic core
Motor
Two-speed
Winding

ABSTRACT

This article addresses the design and manufacturing of two-speed asynchronous motors with pole-changing windings. The need for developing two-speed motors with a single pole-changing winding is justified from the standpoint of energy and resource efficiency, as well as improved starting performance of high-power electric drives. An analysis of existing pole-changing winding designs is presented, highlighting their practical limitations in industrial applications. A new pole-changing winding with a 4/2 pole ratio and 48 stator slots was developed using the discrete spatial functions method based on star–delta–double star configurations. The electromagnetic characteristics of the proposed winding were analyzed. Based on this design, a new 4A200L8/4U3 two-speed motor was manufactured and tested under production conditions at the energy motors plant. Experimental results show that at $p_1 = 4$ pole pairs the motor delivers $P_2 = 20$ kW with efficiency $\eta = 87\%$, $\cos\varphi = 0.82$, $I_1 = 43$ A at slip $s = 2.35\%$, while at $p_2 = 2$ pole pairs it develops $P_2 = 36$ kW with efficiency $\eta = 91.5\%$, $\cos\varphi = 0.906$, $I_1 = 66$ A at slip $s = 1.5$. The results confirm more efficient utilization of the active magnetic core at lower polarity and demonstrate the feasibility of implementing such motors for energy-saving applications in heavy-duty drives requiring two equivalent operating speeds.

Corresponding Author:

Bibigul Issabekova
Department of Automation and Control, Faculty of Energy, Toraighyrov University
Pavlodar 140000, Kazakhstan
Email: issabekova.b@teachers.tou.edu.kz

1. INTRODUCTION

Currently, along with frequency control, electric drives with two-speed motors (DD) have become widespread. These drives have a number of advantages, such as low cost, no additional devices, and ease of control and operation, as well as high efficiency in terms of energy savings with less stringent requirements [1]. DDs with pole ratios of 1/2, 1/3, 1/4, 1/5, and 1/6 are widely used in numerous lifting and transport mechanisms (hoists, elevator installations), metalworking machines (lathes, milling machines, grinding machines), and agricultural machinery (conveyors, screw conveyors, crushers, and AVM-type drying units). In most cases, these mechanisms operate under heavy loads and have a large number of starts (up to 200 per hour).

DD motors with pole ratios of 2/3, 3/4, 4/5, and 5/6 can be used in mechanisms with fan loads (pumps, fans, and centrifugal compressors), in the mining and processing industry (conveyors, feeders, crushers, mills), and in agricultural machinery (separators, drum mills, screening machines). DDs of a particular ratio are used to perform the technological process by the equipment where they are installed, the operating mode of which is determined by many independent factors: climatic and weather conditions, the technological process of industrial enterprises, and the operating mode of organizations, which are usually characterized by work schedules or a cycle diagram for performing a single process.

Two-speed asynchronous motors can also be used to facilitate the start-up of electric motors in harsh conditions [2], [3]. Two-speed asynchronous motors provide a quick start, in which the initial acceleration is carried out at low speed, and then the electric motor switches to high speed [4]. Many of the existing two-speed motors have two or more separate windings on the stator, which requires higher costs than single-winding motors – 30–40% for electrical steel and 40–50% for winding copper, with a corresponding increase in labor intensity. In addition, the efficiency and cosφ of the motor are reduced by an average of 10–15%.

The use of a single pole-changing winding (PCW) with two groups of terminals for each pole allows for more efficient use of the active part of the machine, saves on winding copper and insulating materials, improves energy performance, and makes it possible to bring the mass and size of a two-speed motor closer to those of conventional single-speed asynchronous motors [2]. Windings obtained on the basis of pole-amplitude modulation (PAM) and phase modulation (PM) methods can have significant asymmetry, which can be eliminated by using the summarization method leads to an increase in the number of stator slots, which is not always acceptable. In addition, in many cases, the selectivity of the resulting windings and the values of their winding coefficients are insufficient.

Despite a significant number of scientific works and substantial development of methods for constructing PAMs over the past decades, attempts at their practical application have been successful only in isolated cases due to the large number of output terminals, switching contacts, deteriorated electromagnetic properties, and complex manufacturing technology associated with the production of coils of different types and with different pitches.

This clearly demonstrates the advisability of continuing the search for ways to obtain simple and reliable PCW circuits that meet the requirements of electrical engineering. The current tasks in this area are to minimize the number of terminals and switching contacts, as well as to coordinate magnetic induction values, high technological efficiency, and improved electromagnetic properties. With increasing demands on the quality of finished materials, there is a need to create more advanced motor designs. In these industries, the most important factor is not only high productivity and quality of output, but also high energy efficiency of equipment, which is becoming critically important given rising energy costs and the need to reduce carbon emissions [2].

A distinctive feature of all types of engines is that they are started under difficult conditions, which is one of the significant technical problems. Under the conditions of traditional relay-contactor circuits [2], [3] for controlling electric drives, the mixers are started by repeatedly turning on and off the asynchronous motor, which leads to increased inertia and high resistance moments during start-up. These factors, as shown in [1], require significant energy consumption for startup and can lead to increased wear of equipment, which influences its durability and reliability. This leads to accelerated wear of the mechanical gears and the motor itself and decreases its service life. Two-speed asynchronous motors can also be used to make it easier to start electric motors in demanding conditions. Two-speed asynchronous motors ensure a dry start, wherein the initial acceleration takes place at low speed, and then the electric motor switches to high speed.

Many existing two-speed motors have two or more separate windings on the stator, which impairs their weight, size and power characteristics. The application of a single pole-switched winding in two-speed motors, which has two groups of terminals for each pole, enables one to use the active part of the machine more efficiently, save winding copper and insulating materials, raise energy performance, and makes it possible to advance a two-speed motor in terms of weight and size to conventional serial single-speed asynchronous motors.

Many of the developed circuits of pole-switched windings fail to find practical use due to the large number of terminal ends, switching contacts, degraded electromagnetic properties, as well as complex manufacturing technology associated with coils with various turns and pitch [5]-[13]. Research in the field of asynchronous electric drives and pole-changing windings covers a wide range of tasks: from improving energy efficiency to optimizing the design parameters of machines. Shamsutdinov [1] explained considers ways to modernize the asynchronous drive of ball mills, while [2] systematically develop the concept of pole-changing windings for lifting, transport, and turbomachinery, proposing new winding designs with a close and variable pole ratio. Parallel studies [8], [12]-[15] confirm that the use of optimized pole-changing circuits and the 3//Y–3//Y method improves electromagnetic characteristics, reduces torque ripple, and increases motor stability in transient modes.

An important contribution to motor diagnostics and protection was made by [1], [10], [16], [17], which proposed sensor less control methods, protective devices without current transformers, and diagnostic algorithms using neural networks and search windings. Works [18]-[21] are aimed at improving the energy efficiency of electric drives in oilfield, railway, and industrial installations, including the automation of tests to optimize machine characteristics. Research on multipole and high-speed synchronous motors with permanent magnets has undergone significant development. [7], [22]-[25] demonstrate the influence of the number of slots, coil pitch, and pole shape on the losses, torque, and thermal regime of high-speed machines. The works in [26], [27] investigate specific problems of suspended and contactless motors, as well as the suppression of unbalanced magnetic forces.

Additional areas include loss simulation, optimization of two-pole motor characteristics and methods for increasing the thermodynamic efficiency of electrical systems [28]-[30]. Finally, proposed efficiency maps for wide load ranges, which allow for improving the economic efficiency of asynchronous machines. Current research focuses on improving pole-changing, multi-speed, and high-speed motors, improving their electromagnetic properties, energy efficiency, and reliability. Despite significant progress, there is still a need for more accurate models of electromagnetic processes, unified methods for designing windings, and the integration of analytical methods with numerical modeling, especially when motors are operating in heavy and dynamic modes.

All the presented studies stress the importance of optimizing the design and control characteristics of motors to increase their energy efficiency. The use of new pole-switched windings is one of the key areas for improving the performance of two-speed motors, which allows for a significant reduction in energy losses and increased productivity. The aim of this work is to develop new pole-changing winding schemes and, based on them, to design two-speed motors with improved energy characteristics. The scientific novelty of the work consists of the development of a new pole-changing winding scheme based on the basic "Y-Δ/YY" scheme with a pole ratio of 8/4 at 48 stator slots, which has improved electromagnetic characteristics and consistency of magnetic inductions in the air gap of the machine.

2. METHOD

A new method called "discrete spatial functions" (DSF) was proposed for constructing PCW, based on the joint consideration of current distributions of two or more conventional windings, expressed as discrete spatial functions. The discrete element of the DSF winding is the state of the conductor. This name is assigned to the coil side of the winding with one conventional conductor belonging to one of the winding phases and designated identically with this phase. For example, states a, b, c are conventional conductors with unit currents (or electromotive force (EMF)) in the positive direction in the slots (i.e., "away from us"), belonging to phases A, B, C. The minus sign in front of a, b, and c corresponds to conductors with unit currents (or EMF) in the negative direction in the slots (i.e., "towards us").

The construction of PCW is based on special basic circuits (BC) that have two groups of terminals, and when switching the power supply from one group of terminals to another, the number of pole pairs changes (in relation to one group of terminals, they are $2p_1$-pole, and in relation to the other, they are $2p_2$-pole). When constructing a PCW based on this method using BC "Y/YY", it is possible to consider both m–2m–zone and 2m–2m–zone windings together, and when using BC "YYY/YYY", m–m–zone or 2m–2m–zone windings can be considered together, but the joint consideration of 2m–2m–zone windings often leads to the use of the YYY/YYYYYY busbar [1], [2].

The windings obtained by this method are as close as possible in their electromagnetic and technological properties to normal windings. Let us consider the process of constructing a pole-changing winding with a pole ratio of 8/4 with 48 stator slots. In this case, the current distribution of m–2m–zone windings is considered. The pole-changing winding is constructed on the basis of the Y-Δ/YY connection (see Figure 1), which has two groups of terminals, with terminals A, B, C for $2p_1 = 4$ and terminals D, E, F for $2p_2 = 8$ on the pole side [31], [32].

As the initial winding, we will take an m-zone winding with $p_2 = 4$, and with the number of slots per pole and phase $q_2 = 4$, and as the standard winding, we will take a normal 2m-zone winding with $p_1 = 2$ and $q_1 = 4$. We record the DSF of the lower layer of each winding under each other, then the correlation of the rows will be as shown in Table 1. The resulting circuit of a pole-switched winding is a "Dahlander" circuit [2], [22], [23], [31]. To improve electromagnetic properties, match inductions in the air gap, and symmetry, it is advisable to use additional branches.

The number of coils placed in additional branches may be 17-50% of the total number. Those coils that are ineffective in creating the total EMF of the phase are placed in additional branches. The coils of the additional branches are distributed with the condition of mutual compensation, because when a power source is connected from the pole side, where there are no additional branches, EMFs are induced in them, which contribute to the creation of equalizing currents. The underlined coils shown in Table 1 can be brought-out into additional branches [24]. Record the DSF of the winding from the side of both poles, considering the coils brought out into additional branches (see Tables 2 and 3).

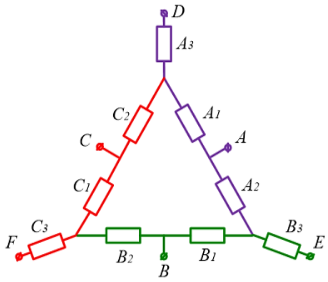


Figure 1. Basic “Y-Δ/YY” diagram

Table 1. DSF of the lower winding layer

Stator slot	Lower-layer DSF (+/−)		Stator slot	Lower-Layer DSF (+/−)	
1	a	a	26	a	a
2	a	a	27	a	a
3	a	a	28	a	a
4	a	a	29	c	-c
5	c	-c	30	c	-c
6	c	-c	31	c	-c
7	c	-c	32	c	-c
8	c	-c	33	b	b
9	b	b	34	b	b
10	b	b	35	b	b
11	b	b	36	b	b
12	b	b	37	a	-a
13	a	-a	38	a	-a
14	a	-a	39	a	-a
15	a	-a	40	a	-a
16	a	-a	41	c	c
17	c	c	42	c	c
18	c	c	43	c	c
19	c	c	44	c	c
20	c	c	45	b	-b
21	b	-b	46	b	-b
22	b	-b	47	b	-b
23	b	-b	48	b	-b
24	b	-b	2p	8	4
25	a	a			

Table 2. DSF of pole-switched winding on minor polarity

Stator slots	Lower-layer DSF (+/−)		Stator slots	Lower-layer DSF (+/−)	
1	-c	a	26		a
2		a	27	b	a
3	b	a	28	b	
4	b		29	b	-c
5	b	-c	30		-c
6		-c	31	-a	-c
7	-a	-c	32	-a	
8	-a		33	-a	b
9	-a	b	34		b
10		b	35	c	b
11	c	b	36	c	
12	c		37	c	-a
13	c	-a	38		-a
14		-a	39	-b	-a
15	-b	-a	40	-b	
16	-b		41	-b	c
17	-b	c	42		c
18		c	43	a	c
19	a	c	44	a	
20	a		45	a	-b
21	a	-b	46		-b
22		-b	47	-c	-b
23	-c	-b	48	-c	
24	-c		2p	4	
25	-c	a			

Table 3. DSF of pole-switched winding on greater polarity

Stator slots	Lower-layer DSF (+/−)				Stator slots	Lower-layer DSF (+/−)			
1		a	-c		26		a	-c	a
2		a	-c	a	27		a	-b	
3		a	-b		28	-b	a	-b	
4	-b	a	-b		29		c	-b	
5		c	-b		30		c	-b	c
6		c	-b	c	31		c	-a	
7		c	-a		32	-a	c	-a	
8	-a	c	-a		33		b	-a	
9		b	-a		34		b	-a	b
10		b	-a	b	35		b	-c	
11		b	-c		36	-c	b	-c	
12	-c	b	-c		37		a	-c	
13		a	-c		38		a	-c	a
14		a	-c	a	39		a	-b	
15		a	-b		40	-b	a	-b	
16	-b	a	-b		41		c	-b	
17		c	-b		42		c	-b	c
18		c	-b	c	43		c	-a	
19		c	-a		44	-a	c	-a	
20	-a	c	-a		45		b	-a	
21		b	-a		46		b	-a	b
22		b	-a	b	47		b	-c	
23		b	-c		48	-c	b	-c	
24	-c	b	-c		2p		*8*		
25		a	-c						

Based on the obtained DSF, we draw up a diagram of the PSW connections: the diagram of the PSW connections is drawn up taking into account the property of the BC (in half of the coils the sign changes, see Table 4) and, considering the first and third rows, based on the state of the signs, the branch corresponding to a particular coil number is determined. The magnetizing force curves (see Figure 2) generated by the PCW on both poles are close to a sine wave, and the winding has fairly high winding coefficients, with $k_1 = 0.691$ on the $2p_1 = 4$ pole side and on the side of $2p_2 = 8$, $k_2 = 0.876$. The winding is completely symmetrical with respect to the power source.

Table 4. Coil grouping in the branch of the BC winding

Coil No.								
A1	B1	C1	A2	B2	C2	A3	B3	C3
4,	12,	8,	13,	21,	5,	1,	9,	17,
16,	24,	20,	14,	22,	6,	2,	10,	18,
28,	36,	32,	15,	23,	7,	3,	11,	19,
40	48	44	37,	45,	29,	25,	33,	41,
			38,	46,	30,	26,	34,	42,
			39	47	31	27	35	43

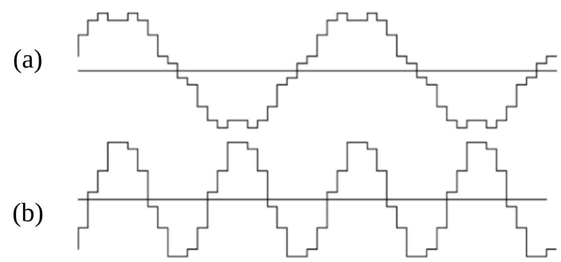


Figure 2. Pictures of magnetizing forces: (a) from the side 2p = 4 and (b) from the side 2p = 8

The coils of each branch (A1…C3) are connected in series according to the grouping in Table 4. The polarity of each subsequent coil is determined by the signs of the DSF (rows 1 and 3). When the signs of adjacent coils match, a matched series connection (end–start) is established. When the sign changes, the coil is connected in reverse (the terminals are flipped), ensuring the desired direction of the resulting magnetomotive force of the branch, taking into account the BC property (sign change in half of the coils).

It is known that in the air gap of an electric machine, along with the fundamental harmonic field, there is also a whole range of higher harmonic fields [31], [32]. The occurrence of higher harmonics is associated with the impossibility of distributing the linear load in space in a strictly sinusoidal manner. The winding is divided into a limited number of zones, as a result of which the shape only approximates a sine wave to a certain degree. This is the reason for the appearance of higher harmonics, whose amplitude decreases with increasing order. Tables 5 and 6 show the results of electromagnetic analysis.

Table 5. Results of electromagnetic analysis on side $2p_1 = 4$

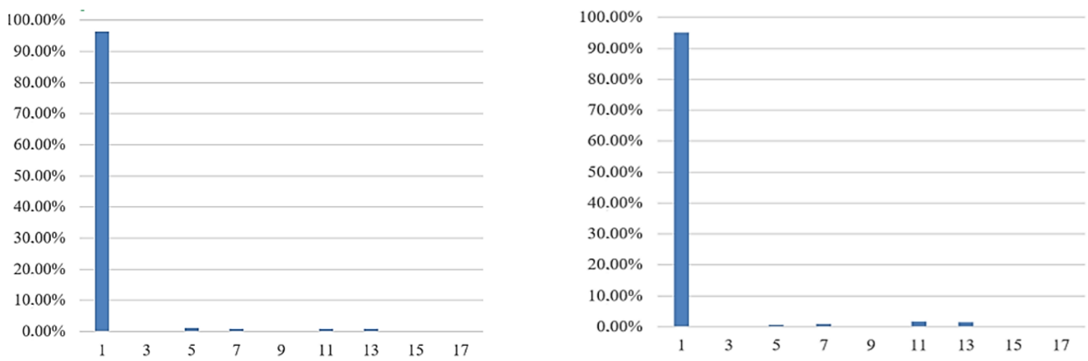
v	Fnm	K_W	Fnm taking into account K_W	Fnm/F∑ ,%, taking into account K_W
1	3.959	0.691	2.736	96.43%
3	0.000	0.569	0.000	0.00%
5	0.082	0.358	0.029	1.03%
7	0.093	0.228	0.021	0.75%
9	0.000	0.098	0.000	0.00%
11	0.114	0.220	0.025	0.89%
13	0.097	0.220	0.021	0.75%
15	0.000	0.098	0.000	0.00%
17	0.038	0.114	0.004	0.15%

Table 6. Results of electromagnetic analysis on side $2p_2 = 8$

v	Fnm	K_W	Fnm taking into account K_W	Fnm/F∑ ,%, taking into account K_W
1	4.125	0.877	3.619	95.06%
3	0.000	0.250	0.000	0.00%
5	0.221	0.108	0.024	0.63%
7	0.158	0.224	0.035	0.93%
9	0.000	0.250	0.000	0.00%
11	0.075	0.877	0.066	1.73%
13	0.063	0.877	0.056	1.46%
15	0.000	0.250	0.000	0.00%
17	0.065	0.108	0.007	0.19%

As can be seen from Tables 5 and 6, as well as Figure 3, the value of the first harmonic is relatively large, and with side $2p_1 = 4$ is equal to 96.43%, and side $2p_2 = 8$ is equal to 95.06%; there are no even harmonics on side $2p^2 = 8$. The shape of the Görges diagrams is close to a circle on both pole sides (see Figure 4), the value of the differential dispersion coefficients is minimal, with $\sigma_0 = 2.0\%$ on the $2p_1 = 4$ side and $\sigma_0 = 1.4\%$ on the $2p_2 = 8$ side.

Figure 5 shows the electrical circuit diagram of the proposed three-phase pole-switched winding with a pole ratio of 8/4. The winding coils are grouped in a delta circuit with additional branches - a double star, wherein coils with serial numbers 4, 16 are connected in series in part $A_{1.1}$, coils with serial numbers 14, 20 are connected in series in part $A_{1.2}$, coils with serial numbers 12, 24 are connected in series in part $B_{1.1}$, coils with serial numbers 36, 48 are connected in series in part $B_{1.2}$, coils with serial numbers 8, 20 are connected in series in part $C_{1.1}$, coils with serial numbers 32, 44 are connected in series in part $C_{1.2}$, coils with serial numbers 13, 14, 15, 37, 38, 39 are connected in series in part A_2, coils with serial numbers 1, 2, 3, 25, 26, 27 are connected in series in part A_3, coils with serial numbers 21, 22, 23, 45, 46, 47 are connected in series in part B_2, coils with serial numbers 9, 10, 11, 33, 34, 35 are connected in series in part B_3, coils with serial numbers 5, 6, 7, 29, 30, 31 are connected in series in part C_2, coils with serial numbers 17, 18, 19, 41, 42, 43 are connected in series in part C_3.



(a) (b)

Figure 3. Histogram of harmonics: (a) from the side 2p = 4 and (b) from the side 2p = 8

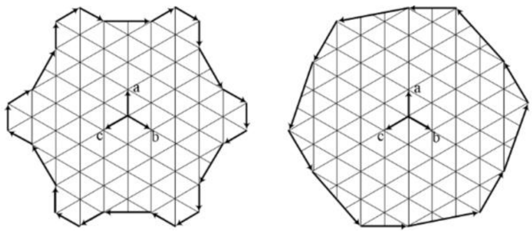


Figure 4. Görges diagrams: (a) from the side 2p = 4 and (b) from the side 2p = 8

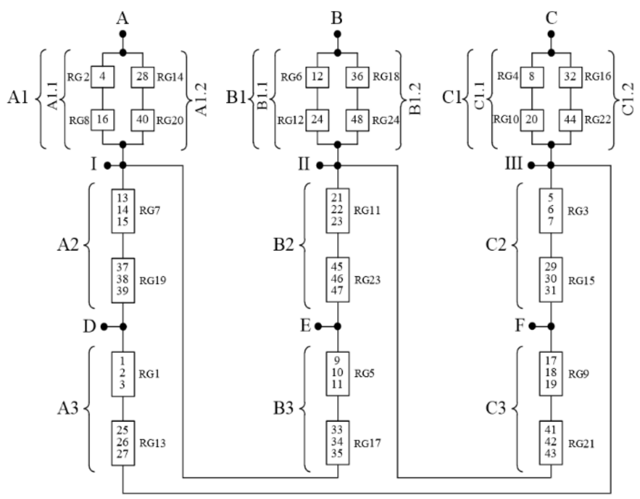


Figure 5. Electrical diagram of the proposed three-phase pole-switched winding with a pole ratio of 8/4

3. RESULTS AND DISCUSSION

Based on the developed PCW diagram using the ANSYS Maxwell program, a two-speed motor was designed, and according to the calculation data at energy motors, an experimental model of a new two-speed motor with a pole ratio of 8/4 was manufactured based on the magnetic circuit of a serial machine of type 4A2. Energy motors, an experimental model of a new two-speed motor with a pole ratio of 8/4 was manufactured based on the magnetic circuit of a serial machine of the 4A200L4UZ type with a stator slot number $Z_1 = 48$ and a rotor slot number $Z_2 = 38$, and a stator package length $l_\delta = 215$ mm. The winding is made with the same number of conductors in each slot $w_n=18$ with enamel-coated winding wire (ECWW) wire $\phi =1.18$ mm. The number of consecutive turns in phase with the number of pole pairs $p_1 = 2$ is $w_2 = 72$, and with the number of pole pairs $p_2 = 4$ is $w_4 = 108$. This ensures a ratio of induction in the air gap of the motor with this winding $B_{\delta 8}/B_{\delta 4} = 1.15$.

To analyze the operation of the designed motor, an accurate mathematical description of the electromagnetic processes occurring in it is required. To do this, we will use the well-known Park-Clark transformations, in which the three-phase coordinate system $(a,,c)$ is transformed into an equivalent two-axis system (α,β): For example, in a three-phase system, instantaneous phase voltages can be expressed as sinusoidal functions (1) of time:

$$\begin{cases} u_a(t) = U_m \cos \omega t \\ u_b(t) = U_m \cos(\omega t - 2\pi/3), \\ u_c(t) = U_m \cos(\omega t + 2\pi/3) \end{cases} \tag{1}$$

where, Um is the maximum phase voltage, ω is the angular frequency.

To convert to an equivalent two-axis conversion, this conversion is expressed as (2).

$$\begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \tag{2}$$

Next, the stationary $\alpha\beta$ components are transformed into a rotating coordinate system as (3).

$$\begin{bmatrix} u_d \\ u_q \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix}, \tag{3}$$

Where $\theta = \omega t$ is the electrical angle showing how much the rotating coordinate system (dq-axis) has rotated during time t.

As a result, sinusoidal voltages in the abc system are converted into constant values in the d-system under steady-state symmetric conditions. To analyze the operation of the motor, it is necessary to create a dynamic model of the machine in the form of state equations, where flux linkages are considered as the main variables:

– Stator flux linkage equations in the dq axes

$$\begin{cases} F_{ds} = \omega_b \psi_{ds} = X_{ls} i_{ds} + X_m(i_{ds} + i_{dr}) \\ F_{qs} = \omega_b \psi_{qs} = X_{ls} i_{qs} + X_m(i_{qs} + i_{qr}) \end{cases}$$

– Rotor flux linkage equations in the dq axes

$$\begin{cases} F_{dr} = \omega_b \psi_{dr} = X_{lr} i_{dr} + X_m(i_{ds} + i_{dr}) \\ F_{qr} = \omega_b \psi_{qr} = X_{lr} i_{qr} + X_m(i_{qs} + i_{qr}) \end{cases}$$

– Equations of magnetizing flux links in axes dq

$$\begin{cases} F_{dm} = \omega_b \psi_{dm} = X_m(i_{ds} + i_{dr}) \\ F_{qm} = \omega_b \psi_{qm} = X_m(i_{qs} + i_{qr}) \end{cases}$$

Where ω_b is the base electrical circular frequency of the machine, $X_{ls} = \omega bLls$, $X_{lr} = \omega bLlr$, and $X_m = \omega bLm$.

When analyzing electromagnetic and electromechanical processes, it is necessary to perform a large number of mathematical calculations, which is possible using computer technology. Therefore, we will use the MATLAB/Simulink environment to simulate a three-phase asynchronous machine. The advantage of the MATLAB/Simulink environment is its ability to perform block modeling, which provides clarity and flexibility in changing the model structure. Figure 6 shows the complete diagram of the proposed model of a three-phase asynchronous machine. This diagram includes both electrical equations and blocks describing the mechanical dynamics of the system. This model is comprehensive and allows for research that is as close as possible to real operating conditions.

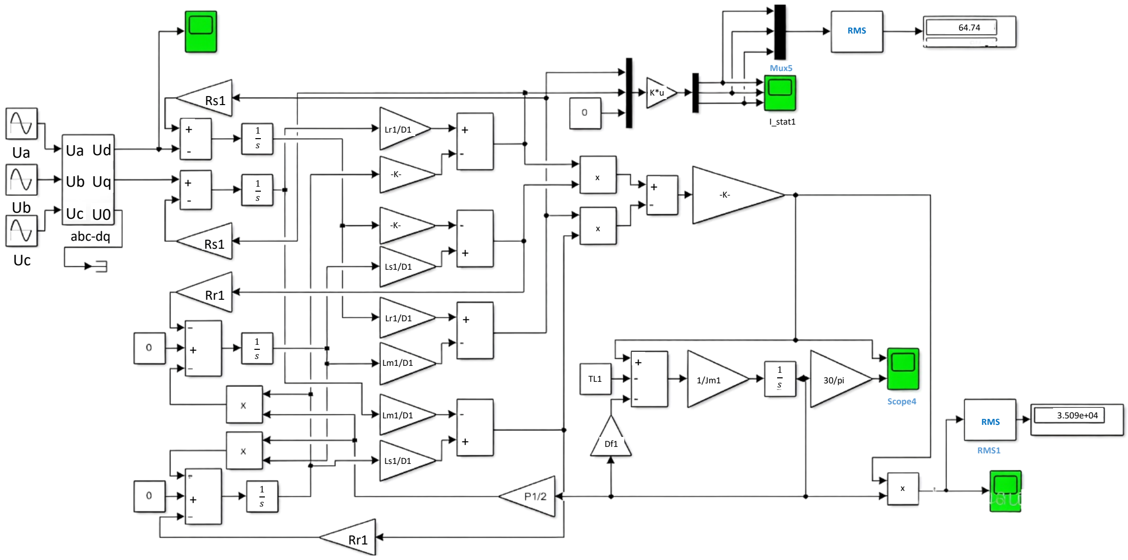


Figure 6. Model of a three-phase asynchronous motor in MATLAB/Simulink environment

The main purpose of modeling is to verify the adequacy of the mathematical description of the machine and to analyze its transient processes. The input parameters for the model were the stator voltage, pole number, stator and rotor winding resistance, stator and rotor leakage inductance, and mutual inductance (see Table 7). Figures 7 and 8 show the characteristics of the transient process of the new two-speed motor obtained using a three-phase asynchronous machine model in the MATLAB/Simulink environment. As can be seen in Figure 7, the transition process of a two-speed motor during direct start from side $2p_1 = 4$ lasts in the time interval from $t = 0$ to $t \approx 0.4$ s with significant current fluctuations with an amplitude of about ±452 A, which is 6.9 times higher than the rated current of the machine ($I \approx 64.7$) with a shaft load of 230 N*m. In steady state, the machine develops a torque of 235 N at a speed of 1448 revolutions per minute.

As can be seen in Figure 8, the transition process of a two-speed motor during direct start from side $2p_2 = 8$ lasts in the time interval from $t = 0$ to $t \approx 0.14$ s with significant current fluctuations with an amplitude of about ±260 A, which is 6.18 times higher than the rated current of the machine ($I \approx 43$) with a shaft load of 260 N*m. In steady state, the machine develops a torque of 265 N*m at a speed of 731 rpm. Experimental studies of the new 4A200L8/4U3 two-speed motor were conducted in the test laboratory of energy motors. The test bench consists of three main parts (Figure 9): 1 - control cabinet; 2 - load bench for engines from 22 kW to 45 kW; 3 - personal computer with specialized software (operator's workstation).

The DMG digital multimeter measures currents, voltages, and other electrical characteristics. The voltage level is set by a computer. The multimeter also measures the power consumed by the electric motor. The information from the multimeter is sent to the computer, to the “Test It!” program. The test bench has a built-in industrial controller that switches the relay-contactor equipment according to commands from the “Test It!” program. A 132 kW load motor controlled by frequency converters is used to load the electric motor under test. The braking energy is dissipated by resistors installed in the test bench. The load torque of the electric motor under test is set by a computer. Torque is measured by torque sensors connecting the shafts of the electric motor under test and the load motor. When the automatic electric motor test is started, a user-defined sequence of actions is performed to determine the parameters of the electric motor. During the complete test sequence, the insulation of the electric motor is checked while the electric motor is idling, during a short circuit (with the rotor locked), and during the start and operation of the electric motor under load. Repeating the experiments ensured the reliability of the experimental data, equal to 0.97. Based on the results of processing the experimental data, the numerical characteristics of these parameters were determined, and the correctness of the theoretical conclusions was evaluated. The results of processing the experimental data are summarized in Table 8.

Table 7. Input parameters of an asynchronous motor for calculating transient processes in MATLAB/Simulink

Parameter	Value	
	$2p_1 = 4$	$2p_2 = 8$
Stator winding resistance, Rs, Ω	0.12	0.401
Rotor winding resistance, Rr, Ω	0.149	0.368
Stator leakage inductance, Lls, mH	1.207	1.805
Rotor leakage inductance, Llr, mH	1.307	2.3
Mutual inductance, Lm, mH	18.07	23.6

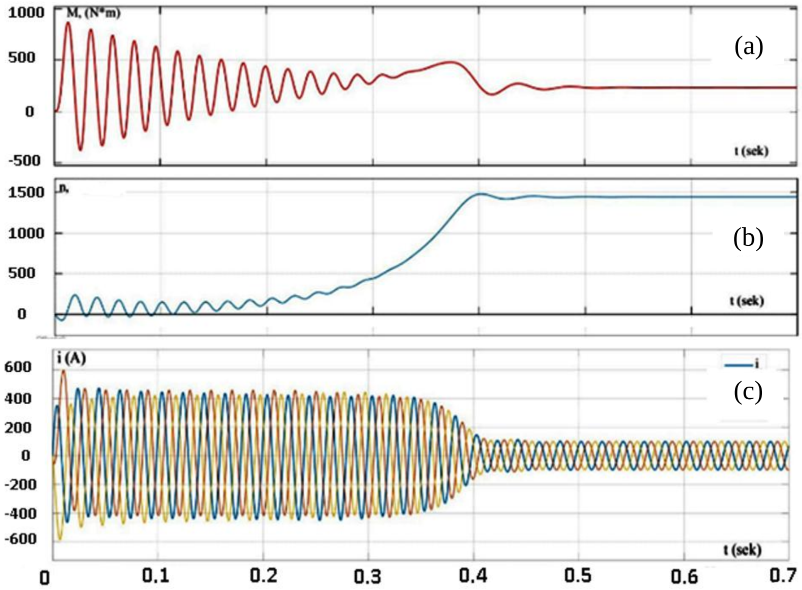


Figure 7. Characteristics of the transition process of a two-speed motor from the side of $2p_1 = 4$: (a) torque variation curve, (b) speed variation curve, and (c) current change curve

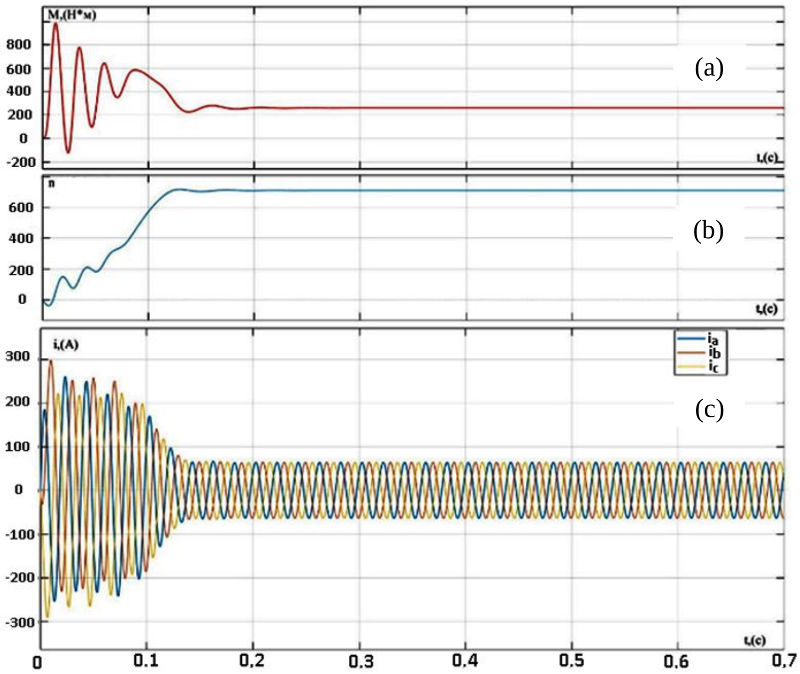


Figure 8. Characteristics of the transition process of a two-speed motor from the side of $2p_2 = 8$: (a) torque variation curve, (b) speed variation curve, and (c) current variation curve

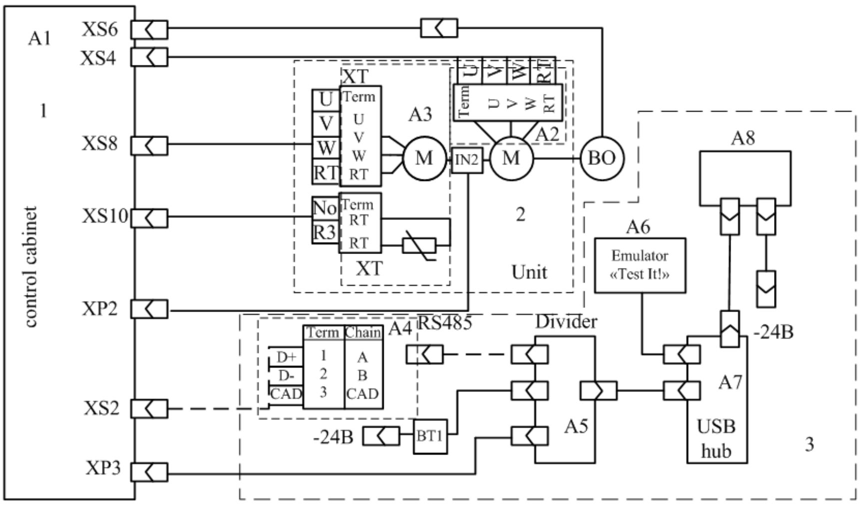


Figure 9. Schematic diagram of the test bench

Table 8. Performance capability data

No	P_1 kW	U_1 V	I_1 A	P_{el1} W	$P_{st}+P_{mech}$ W	P_{el} W	P_g W	P_2 kW	η %	cos φ	M N·m	n min^{-1}	s %
						from p = 2 side							
1	6.3	380	18	122	951.9	11	15	5.2	82.5	0.538	33	1497	0.2
2	14>6	380	27.6	287	951.9	69	34	13.2	90.8	0.801	84.7	1493	0.5
3	22.6	380	39.1	576	951.9	172	69	20.8	92.2	0.876	133.6	1488	0.8
4	27.7	380	46.9	832	951.9	263	100	25.6	92.3	0.895	164.4	1485	1.0
5	32.7	380	54.8	1133	951.9	372	136	30.1	92.1	0.903	193.7	1482	1.2
6	39.7	380	66.3	1661	951.9	563	199	36.3	91.5	0.906	234.7	1478	1.5
7	46.2	380	77.5	2267	951.9	782	271	41.9	90.8	0.903	271.9	1473	1.8
8	50.2	380	84.7	2707	951.9	941	324	45.3	90.2	0.899	294.6	1470	2.0
						from p = 4 side							
1	2.9	380	18.3	401	430	4	21	2.0	69.9	0.236	25.4	748.5	0.2
2	6.0	380	20.1	483	430	26	25	5.1	84	0.456	64.8	746.3	0.5
3	11.1	380	25.2	763	430	101	40	9.8	88	0.67	126.1	742.5	1.0
4	15.9	380	31.6	1201	430	216	63	14.0	88	0.765	181.5	738.8	1.5
5	20.4	380	38.3	1767	430	366	92	17.7	87	0.806	230.6	735	2.0
6	23.3	380	43	2225	430	488	116	20.0	86	0.82	261.2	732.4	2.35
7	24.5	380	45	2434	430	543	127	20.9	85.6	0.824	273.4	731.3	2.5
8	28.1	380	51.4	3175	430	740	166	23.6	84	0.829	310.1	727.5	3.0

4. RESULTS AND DISCUSSION

As shown by experimental studies of the new 4A200L8/4U3 motor with $p_1 = 2$ pole pairs, the useful power reaches a value of $P_2 = 20$ kW at an efficiency of $\eta = 86\%$, cos $\varphi = 0.82$, $I_1 = 43$ A at slip s = 2.35%, and on the $p_2 = 4$ pole pair side, the motor can develop a power of $P_2 = 36$ kW at an efficiency of $\eta = 91.5\%$, cos $\varphi = 0.906$, $I_1 = 66$ A at slip s = 1.5%. Figure 10 shows the performance capabilities of the new two-speed motor from both poles, constructed based on the results of experimental studies. The results of experimental tests of mechanical characteristics are summarized in Table 9. The mechanical characteristics of the new two-speed engine are shown in Figure 11.

As can be seen in Figure 11, for both numbers of pole pairs, the mechanical characteristics have sufficient rigidity (nominal slips on the $2p_1$ side = 4 s = 1.5 and on the $2p_2$ side = 8 s = 2.35%) and a smooth appearance. For research in industrial conditions, the new two-speed motor was installed in the drive of a two-shaft mixer of the VL-400-VRU type. Scientific and production association (SPA) of the mining enterprise Almalyk Mining and Metallurgical Company JSC. A LeCroy WR 64Xi digital oscilloscope was used to measure the current curves in the phases on both poles, which allows the current change curves of all three phases to be recorded simultaneously (Figure 12). It should be noted that the currents of the phases on both sides of the poles had identical values and a strictly defined shift between the phases (Figure 13). This confirms the complete symmetry of the obtained PCW in relation to the power supply network. To assess the effectiveness of the developed PSW, a comparison was made between the experimental data of the two-speed motor under study and the parameters of serially produced single-speed and two-speed motors of the same size, having identical rotation frequencies (see Table 10).

Table 9. Mechanical characteristics data

No	From *p* = 2 side		From *p* = 4 side	
	M^*	n, min^{-1}	M^*	n, min^{-1}
1	0	1500	0	750
2	0.7	1485	0.5	743
3	1	1478	1	732
4	2.1	1440	1.9	705
5	2.3	1398	2.1	675
6	2.2	1350	2.1	653
7	1.9	1275	2.1	600
8	1.7	1200	1.9	525
9	1.4	1050	1.8	450
10	1.2	900	1.7	375
11	1.1	750	1.6	300
12	1.1	600	1.6	225
13	1.0	450	1.6	150
14	0.9	150	1.5	75
15	0.9	0	1.3	0

(a)
(b)

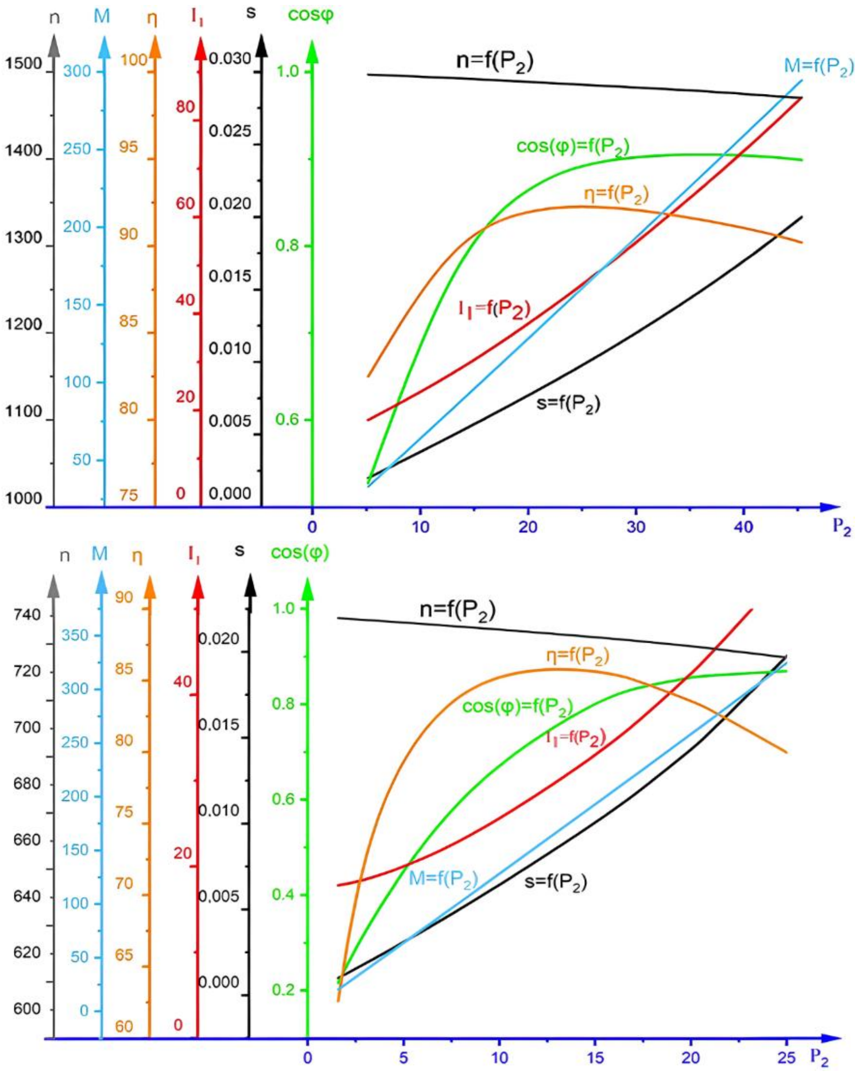


Figure 10. Performance capabilities of the new two-speed motor: (a) from the $2p_1$ side = 4 poles and (b) from the $2p_2$ side = 8 poles

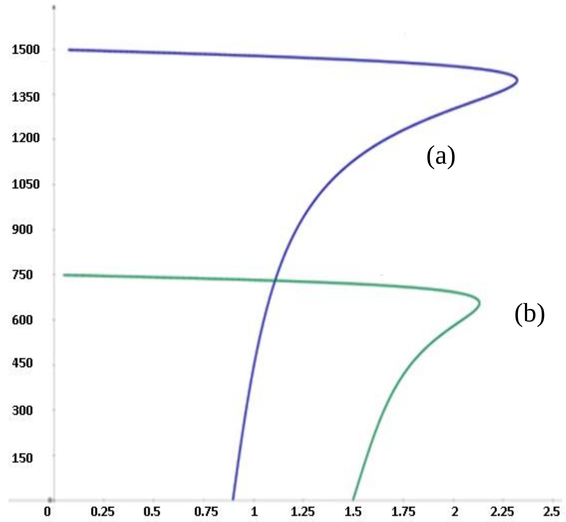


Figure 11. Mechanical characteristics of the new two-speed motor: (a) from the $2p_1$ side = 4 poles and (b) from the $2p_2$ side = 8 poles

Figure 12. Illustration of experimental testing at Almalyk Mining and Metallurgical Company JSC

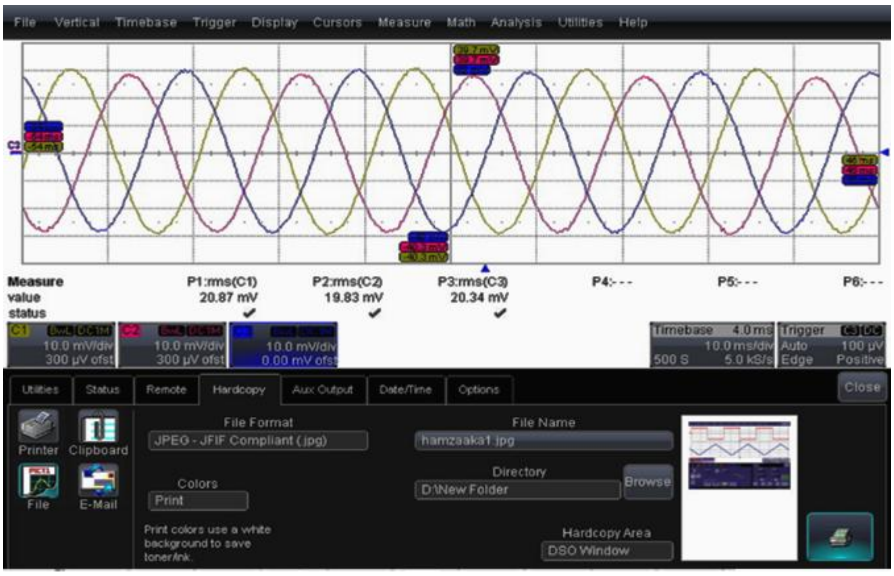


Figure 13. Current curves in phases recorded using a LeCroy WR 64Xi digital oscilloscope

Table 10. Comparison of the parameters of the new two-speed engine with the parameters of existing machines

No	Parameter	UOM	New two-speed motor		Existing two-speed motor		Existing single-speed motors	
	Motor brand		4A200L8/4UZ		4A200L8/4UZ		4A200L8UZ	4A200L4UZ
	Polarity		$p = 4$	$p = 2$	$p = 4$	$p = 2$	$p = 4$	$p = 2$
1	Axle height	mm	200		200		200	200
2	Outer diameter of stator	mm	349		349		349	349
3	Inner diameter of stator	mm	238		250		250	238
4	Air gap	mm	0,70		0,50		0.50	0,70
5	Number of stator/rotor slots		48/38		72/58		72/58	48/38
6	Length of stator and rotor pack	mm	215		185		185	215
7	Net power	kW	20	36	20	28	22	45
8	Stator current	A	43	66	45	53	45	83
9	Efficiency	%	86	91.5	86	88	88.5	92
10	$\cos\varphi$		0.82	0.91	0.77	91	0.84	0.9
11	Slip	%	2.35	1,5				
12	Number of turns in phase		108	72	204	102	114	56
13	Mass of insulated wires of the stator winding	kg	16.6		16.1		13.8	19.5

5. CONCLUSION

The comparison showed that the new two-speed motor develops a useful power of 36 kW on the p = 2 side, which is 80%, and 20 kW on the p=4 side, which is 90.9% of the rated power of single-speed motors of the 4A200L4UZ and 4A200L8UZ types, respectively. In relation to the useful power of the two-speed motor of the 4A200L8/4UZ type, the power developed by the new two-speed motor on the p = 2 side exceeds it by 22.2% with equal power on the p=4 side, manufactured by the Yaroslavl Electric Machine Building Plant ELDIN. This indicates that the power of the new two-speed motor is as close as possible to the power of single-speed motors and greatly exceeds the power of the existing two-speed motor of the same size.

This indicates that motors with a single PCW on the stator achieve a significant increase in useful power and a more efficient use of the active part of the electric machine on the side with lower polarity. Thus, the results of experimental studies of the two-speed motor confirm the possibility of widespread introduction of such motors for energy and resource savings to replace single-speed motors for drives of mechanisms with intense operation, where both speeds of rotation are equivalent, and also show the advantage of the new two-speed pole-changing winding, the use of which improves the characteristics of the two-speed motor.

FUNDING INFORMATION

The paper was prepared with the support of the Ministry of Education and Science of the Republic of Kazakhstan (grant No. AP23486411 "Development of relay line protection against single-phase earth faults in a bundle of cables using "Internet of Things" technology").

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Zhanat Issabekov		✓	✓	✓	✓	✓			✓				✓	✓
Dauletbek Rismukhamedov	✓			✓	✓					✓	✓	✓		
Khusniddin Shamsutdionov	✓	✓				✓	✓			✓	✓			
Shakhobiddin Husanov		✓	✓		✓		✓	✓		✓	✓		✓	
Sabit Rismukhamedov	✓						✓	✓	✓		✓			
Bibigul Issabekova			✓			✓	✓	✓		✓	✓	✓		
Assemgul Zhantlessova				✓	✓	✓			✓				✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

Derived data supporting the findings of this study are available from the corresponding author, [AZ], on request.

REFERENCES

[1] K. Shamsutdinov, "Study on improving the asynchronous electric drive of ball mills," *E3S Web of Conferences*, vol. 497, p. 01001, Mar. 2024, doi: 10.1051/e3sconf/202449701001.
[2] M. K. Bobojanov, D. A. Rismukhamedov, K. F. Shamsutdinov, S. T. Ganiev, M. B. Peysenov, and S. D. Rismukhamedov, "Development of a pole-changing winding for close pole ratio," in *AIP Conference Proceedings*, 2024. doi: 10.1063/5.0219624.
[3] B. Issabekova, M. Tokombaev, and A. Zhantlessova, "Reed switch protection devices with symmetric component filter without current transformers," in *2021 International Ural Conference on Electrical Power Engineering (UralCon)*, Sep. 2021, pp. 141–146. doi: 10.1109/UralCon52005.2021.9559592.
[4] Z. B. Issabekov, M. Y. Kletsel, A. S. Barukin, and B. E. Mashrapov, "Measuring bodies for distance protection that does not use current transformers," in *AIP Conference Proceedings*, 2021, p. 030003. doi: 10.1063/5.0047155.
[5] E. Libbos, S. Chaubal, A. Maheshwari, A. Banerjee, and P. T. Krein, "Bumpless electronic pole-changing for variable-pole induction machines," *IEEE Transactions on Transportation Electrification*, vol. 11, no. 1, pp. 1201–1213, Feb. 2025, doi: 10.1109/TTE.2024.3401613.
[6] K. Bitsi, S. G. Bosga, and O. Wallmark, "Design aspects and performance evaluation of pole-phase changing induction machines," *Energies*, vol. 15, no. 19, p. 7012, Sep. 2022, doi: 10.3390/en15197012.
[7] Rohith, L. Umanand, and S. R. B., "Pole changing wide speed range induction motor drive for electric vehicles," in *2018 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)*, Dec. 2018, pp. 1–5. doi: 10.1109/PEDES.2018.8707677.
[8] L. Guo, Y. Yang, and H. Wang, "Multi-pole ratio single-winding pole-changing permanent magnet motor design and analysis," *Journal of Power Electronics*, vol. 24, no. 12, pp. 1979–1989, Dec. 2024, doi: 10.1007/s43236-024-00870-w.
[9] T. Latif, M. Z. M. Jaffar, and I. Husain, "Modeling and control of a 4-pole/8-pole induction motor for smooth torque production during electronic pole changing," in *2020 IEEE Energy Conversion Congress and Exposition (ECCE)*, Oct. 2020, pp. 2052–2057. doi: 10.1109/ECCE44975.2020.9236133.
[10] S. V. S. P. K. Ch, V. Sonti, and S. Jain, "Pole-phase modulated open-end winding induction motor drive with gradual pole changing technique for EV application," in *2022 Second International Conference on Power, Control and Computing Technologies (ICPC2T)*, Mar. 2022, pp. 1–5. doi: 10.1109/ICPC2T53885.2022.9776742.
[11] A. Miniyarov and A. Podguzov, "Methods of current diagnostics of asynchronous motors with combined stator winding," in *2020 International Conference on Electrotechnical Complexes and Systems (ICOECS)*, Oct. 2020, pp. 1–4. doi: 10.1109/ICOECS50468.2020.9278443.
[12] L. Hao, J. Wu, and Y. Zhou, "Theoretical analysis and calculation model of the electromagnetic torque of nonsalient-pole synchronous machines with interturn short circuit in field windings," *IEEE Transactions on Energy Conversion*, vol. 30, no. 1, pp. 110–121, Mar. 2015, doi: 10.1109/TEC.2014.2350336.
[13] S. Ibrir and H. Al-Abudib, "Speed tracking of induction motors with symmetric dead-zone inputs," in *2017 14th International Multi-Conference on Systems, Signals & Devices (SSD)*, Mar. 2017, pp. 796–801. doi: 10.1109/SSD.2017.8167016.
[14] G. Kovacs, "Calculation of synchronous torques and radial magnetic forces for pole-changing winding using the 3//Y / 3//Y method," in *2020 International Conference on Electrical Machines (ICEM)*, Aug. 2020, pp. 90–96. doi: 10.1109/ICEM49940.2020.9270765.
[15] G. Kovacs, "Pole-changing windings for close ratio and 1:N ratio Using the 3//Y / 3//Y method," *Advances in Science, Technology and Engineering Systems Journal*, vol. 3, no. 4, pp. 241–253, Aug. 2018, doi: 10.25046/aj030424.
[16] M. T. Joy and J. Bocker, "Speed estimation in induction machines at all speed ranges using sensing windings," in *2018 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)*, Dec. 2018, pp. 1–6. doi: 10.1109/PEDES.2018.8707494.
[17] A. T. Radhi and W. H. Zayer, "Faults diagnosis in stator windings of high speed solid rotor induction motors using fuzzy neural network," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 12, no. 1, p. 597, Mar. 2021, doi: 10.11591/ijpeds.v12.i1.pp597-611.
[18] D. Vishnyakov, E. Solodkiy, and S. Salnikov, "Improving Sucker-rod pump energy efficiency through electric drive movement control," in *2021 28th International Workshop on Electric Drives: Improving Reliability of Electric Drives (IWED)*, Jan. 2021, pp. 1–3. doi: 10.1109/IWED52055.2021.9376317.
[19] G. A. Fedyaeva, Y. M. In'kov, A. G. Nadtochey, and D. V. Konokhov, "Improving the energy efficiency of asynchronous traction electric drive locomotives," *Russian Electrical Engineering*, vol. 93, no. 9, pp. 610–615, Sep. 2022, doi: 10.3103/S1068371222090061.
[20] A. Agapov, Y. Krylov, S. Belozorov, T. Chernykh, A. Litvinenko, and A. Tikunov, "The research and optimization of the executive electric motor of the supervision electric drive within the general concept of energy efficiency," in *2023 5th International Conference on Control Systems, Mathematical Modeling, Automation and Energy Efficiency (SUMMA)*, Nov. 2023, pp. 1024–1027. doi: 10.1109/SUMMA60232.2023.10349461.
[21] Y. O. Teplova, V. D. Koldaev, and N. L. Aung, "Improving induction motors energy efficiency characteristics control methods by using testing processes automation for purposes of energy-efficient electrical machines development," in *2020 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus)*, Jan. 2020, pp. 2425–2430. doi: 10.1109/EIConRus49466.2020.9039324.

[22] T. He, Z. Q. Zhu, F. Xu, Y. Wang, H. Bin, and L. Gong, "Electromagnetic performance analysis of 6-slot/2-pole high-speed permanent magnet motors with coil-pitch of two slot-pitches," *IEEE Transactions on Energy Conversion*, vol. 37, no. 2, pp. 1335–1345, Jun. 2022, doi: 10.1109/TEC.2021.3125005.

[23] F. Xu *et al.*, "Influence of Slot number on electromagnetic performance of 2-pole high-speed permanent magnet motors with toroidal windings," *IEEE Transactions on Industry Applications*, vol. 57, no. 6, pp. 6023–6033, Nov. 2021, doi: 10.1109/TIA.2021.3117739.

[24] F. Xu *et al.*, "Comparison of Slotted and Slotless High-Speed Permanent Magnet Motors with Toroidal Windings," in *2022 IEEE Energy Conversion Congress and Exposition (ECCE)*, Oct. 2022, pp. 1–8. doi: 10.1109/ECCE50734.2022.9947659.

[25] K. Haruki and Y. Iwaji, "High-efficiency drive technology for high-speed, multi-pole motors with minor sampling process," in *2024 27th International Conference on Electrical Machines and Systems (ICEMS)*, Nov. 2024, pp. 1239–1244. doi: 10.23919/ICEMS60997.2024.10920988.

[26] T. Matsuzaki, M. Takemoto, S. Ogasawara, S. Ota, K. Oi, and D. Matsuhashi, "Operational characteristics of an IPM-type bearingless motor with 2-pole motor windings and 4-pole suspension windings," *IEEE Transactions on Industry Applications*, vol. 53, no. 6, pp. 5383–5392, Nov. 2017, doi: 10.1109/TIA.2017.2746668.

[27] T. Fukushima and M. Ooshima, "Combination of pole number of motor and suspension windings and the influence on suspension force in bearingless motors," in *2020 23rd International Conference on Electrical Machines and Systems (ICEMS)*, Nov. 2020, pp. 44–49. doi: 10.23919/ICEMS50442.2020.9290969.

[28] D. G. Dorrell, A. Salah, and Y. Guo, "The detection and suppression of unbalanced magnetic pull in wound rotor induction motors using pole-specific search coils and auxiliary windings," *IEEE Transactions on Industry Applications*, vol. 53, no. 3, pp. 2066–2076, May 2017, doi: 10.1109/TIA.2017.2672748.

[29] M. Olivo, M. Bortolozzi, A. Tessarolo, and F. Luise, "A new method for the accurate prediction of on-load power factor in two-pole induction motors considering shaft eddy currents," *IEEE Transactions on Energy Conversion*, vol. 35, no. 3, pp. 1196–1207, Sep. 2020, doi: 10.1109/TEC.2020.2976617.

[30] O. Stiscia, S. Rubino, S. Vaschetto, A. Cavagnino, and A. Tenconi, "Off-line efficiency mapping of induction motors operated in wide torque-speed ranges," in *2020 IEEE Energy Conversion Congress and Exposition (ECCE)*, Oct. 2020, pp. 1075–1082. doi: 10.1109/ECCE44975.2020.9236081.

[31] D. Rismukhamedov, K. Shamsutdinov, S. Ganiev, K. Magdiev, and S. Khusanov, "New pole-changing winding for electric drive of ball mills," *E3S Web of Conferences*, vol. 384, p. 01059, Apr. 2023, doi: 10.1051/e3sconf/202338401059.

[32] M. Bobojanov, "Induction machine with pole-changing winding for turbomechanisms," *Archives of Electrical Engineering*, pp. 415–428, Jun. 2023, doi: 10.24425/aee.2023.145417.

BIOGRAPHIES OF AUTHORS

Zhanat Issabekov is professor in the Department of Automation and Control at Toraighyrov University, Pavlodar, Kazakhstan. In 2018, he was awarded a Ph.D. in Electric Power Engineering after successfully defending his doctoral dissertation. He began his academic career in 2003 as a senior lecturer at the Department of Computer Systems and Automation at S. Toraighyrov Pavlodar State University. In 2004, he joined the Department of Computer Engineering and Programming, and since 2012, he has been working as a senior lecturer at the Department of Automation and Control. He is the author of more than 45 scientific publications. His research interests include automation systems, control theory, electric power systems, and intelligent control technologies. He can be contacted at email: isabekov.g@teachers.tou.edu.kz.

Dauletbek Rismukhamedov is an acting professor at the Department of Electrical Engineering and Electromechanics, Almalyk branch of Tashkent State Technical University, Uzbekistan. In 2006, he defended his Candidate's dissertation in major 05.09.01 - Electrical Machines, and received a Candidate of Technical Sciences Diploma in 2007. From 2000 to 2006, he worked as an assistant at the Power Supply Department of Tashkent State Technical University, in 2006-2009 as a senior lecturer, in 2009-2016 as an associate professor of the same department, from 2016 to 2017 he headed the Department of Management and Control of Energy Systems of Tashkent State Technical University, in 2018-2020 he studied in internal doctoral programme at Tashkent State Technical University with day shift education, from 2021 to 2023 he headed the Department of Mining Electromechanics of Almalyk branch of Tashkent State Technical University, from 2023 to the present he has been working as an acting professor of the Department of Electrical Engineering and Electromechanics of Almalyk branch of Tashkent State Technical University. The research interests are related to increasing the energy efficiency of electric drives by using pole-switched asynchronous motors. The author of over 100 publications, including over 6 publications in editions cited by Scopus, 19 intellectual property subject matters, the head of the 1st project of the Ministry of Higher Education, Science and Innovation of the Republic of Uzbekistan, and the executor of 2 business contracts. He can be contacted at email: drismuxamedov@gmail.com.

Khusniddin Shamsutdinov is an associate professor at the Department of Electric Power Stations, Networks and Systems, Tashkent State Technical University, Uzbekistan. He graduated from Tashkent State Technical University in 2006 with a bachelor's degree majoring in Electric Power Engineering and in 2008 graduated from the same university with a master's degree majoring in Electric Power Supply. Since 2012, he worked as an assistant at the Department of Electric Stations, Networks, and Systems at Tashkent State Technical University, and since 2014, as a senior lecturer at the same department. In 2022, he completed the basic doctoral program at Tashkent State Technical University, and in 2023, he defended his thesis for Doctor of Philosophy (Ph.D.) in technical sciences, majoring in 05.05.02 - Electrical Engineering. Electric power stations, systems. Electric technical complexes and installations. Since 2023, he has been working as an associate professor at Tashkent State Technical University at the Department of Electric Stations, Networks and Systems. The area of research expertise is related to electrical machines, namely pole-switched windings. The author of over 70 publications, including 5 intellectual property subject matters, 7 publications in editions cited by Scopus. He can be contacted at email: shamsutdinov_husniddin@bk.ru.

Shakhobiddin Husanov is currently a doctoral student at Tashkent State Technical University. He graduated from Tashkent State Technical University in 2016 with a bachelor's degree in Power Engineering and in 2018 with a master's degree in Energy Saving from the same university. From 2018 to 2022, he worked as an assistant at the Department of Electrical Engineering and Electromechanics of the Almalyk branch of Tashkent State Technical University. From 2023 to the present, he has been studying in the basic doctoral program at Tashkent State Technical University with a day shift education. The area of expertise is related to energy saving of economic sectors by improving electric drives. The author of over 10 publications, including over 3 publications in editions cited by Scopus, 1 intellectual property object, is the executor of 2 projects of the Ministry of Higher Education, Science and Innovation of the Republic of Uzbekistan. He can be contacted at email: shahobiddinhusanov0809@gmail.com.

Sabit Rismukhamedov is currently an assistant at the Department of Electrical Engineering, Tashkent State Technical University, Uzbekistan. He graduated from Tashkent State Technical University with a bachelor's degree in Electrical Engineering, Electromechanics and Electrical Technology in 2018 and a master's degree in Power Supply from the same university in 2020. From 2021 to the present, he has been working as an assistant at the Electrical Engineering Department of Tashkent State Technical University. The area of expertise is related to the development of pole-switched winding circuits for multi-speed asynchronous motors. The author of over 15 publications, including over 2 publications in editions cited by Scopus, 5 intellectual property objects, is the executor of 2 projects of the Ministry of Higher Education, Science and Innovation of the Republic of Uzbekistan. He can be contacted at email: sabitrismukhamedov1996@gmail.com.

Bibigul Issabekova is a professor in Electrical Engineering and currently works in the field of automation and power systems. She completed postgraduate studies at Omsk State Technical University in 2013, specializing in power plants and electric power systems. Her Ph.D. thesis focused on determining soil temperature and humidity for calculating soil electrical resistivity. In 2014, she was awarded the degree of Candidate of Technical Sciences of the Russian Federation. From 2014 to 2016, she pursued a second higher education at Pavlodar State Pedagogical Institute, majoring in English. In 2017, she earned a Ph.D. in Electrical Engineering. She is the author of more than 39 scientific publications. Her research interests include energy systems, automation, and soil electrical properties. She can be contacted at email: issabekova.b@teachers.tou.edu.kz.

Assemgul Zhantlessova is a professor at S. Seifullin Kazakh Agro Technical University, Kazakhstan. In 2013, she completed postgraduate studies at Tomsk Polytechnic University, specializing in power plants and electric power systems (05.14.02). In 2015, she was awarded a Ph.D. in electrical engineering. From 2007 to 2010, she worked at Toraighyrov University, and from 2010 to 2015 at Tomsk Polytechnic University. Since 2015, she has been serving as a senior lecturer at S. Seifullin Kazakh Agro Technical University. Her research interests include modeling operating modes of electric power system elements, energy conservation, and improving energy efficiency in electrical networks and power supply systems. She is the author of more than 55 scientific publications. She can be contacted at email: a.zhantlessova@kazatu.edu.kz.