ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 2, February 2025

Development and analysis of 5/6 pole-change winding for multi-speed motors

Rismukhamedov Dauletbek Amonovich, Tuychiev Furkat Numonovich, Magdiev Khayotullo Gaybullo ugli

Professor, Tashkent state technical university, Tashkent, Uzbekistan
Assistant Professor, Tashkent state technical university, Tashkent, Uzbekistan
Assistant Professor, Tashkent state technical university, Tashkent, Uzbekistan

ABSTRACT: In the paper the method for receiving and the detailed analysis of electromagnetic properties pole-changing windings for the pole pairs ratio 5/6 in the 54 stator slots is presented by method discretely specified spatial functions. The new winding is intended for applying in mechanisms with the fan by type of loading with a view of power- and savings resource.

I. INTRODUCTION

Improvement of the energy efficiency of enterprises and economy sectors is one of the pressing problems on a global scale. In Uzbekistan, systematic work is also being carried out, in particular, a number of resolutions of the Cabinet of Ministers of the Republic of Uzbekistan have been adopted: No. 211 "On measures to implement the project "Improvement of the energy efficiency of industrial enterprises" with the participation of International Development Association" dated July 25 2011, which laid the foundation for the introduction of energy-saving technologies.

The creation of two-speed electric machines, by approaching in their energy and weight and size indicators to conventional single-speed machines, makes it possible to improve existing electric drives with two speed motors (TSM) and to replace some single-speed motors of TSM in order to save electricity and natural resources in low-load modes, as well as to facilitate the start-up process of powerful engines [1].

The analysis of existing methods and the study of foreign experience in the design of electric machines showed that at present there is no single method for designing a single pole-changing winding (PCW), although such engines are produced by many electric machine-building plants in foreign countries. In practice, TSM with PCW are widely used, developed according to the Dalander scheme and the pole-amplitude modulation PAM method [2,3].

II. METHODS AND MATERIALS

Professor H.G. Karimov developed a new method for constructing PCW schemes using discretely specified spatial functions (DSSF). Many PCW schemes based on this method have been developed for a wide range of pole-to-phase ratios, close in their properties to the windings of single-speed serial motors [4,5].

The new principle based on this method for current or phase distributions of two simple lap windings of normal execution (i.e. windings which are the most widespread in electromechanical engineering and having high electromagnetic properties) with the number of pole pairs p_1 and p_2 and phases m_1 and m_2 relies [6,7].

Let's consider the construction of PCW on the most relevant 5/6 pole pair ratio, located in 54 stator slots [8]. For the initial windings, we take two two-layer loop *m*-zone stator windings, placed in 54 stator slots, with the numbers of pole pairs p_1=5 and p_2=6, in steps of y = 1-6 and y = 1-5, respectively. In accordance with the detailed scheme, the DSSF of each winding is obtained separately (table 1 and table 2):

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 2, February 2025

Table 1. An expanded scheme of DSSF winding p = 5 sides.

Stator slots															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
-b	-c	-c	-c	-c	-a	-a	-a	-a	-b	-b	-b	-c	-c	-c	-a
a	a	a	a	b	b	b	c	c	c	a	a	a	b	b	b

Stator slots													
17	18	19	20	21	22	23	24	25	26	27	28	29	30
-a	-a	-b	-b	-b	-b	-c	-c	-c	-c	-a	-a	-a	-a
b	c	c	c	c	a	a	a	a	b	b	b	b	c

Stator slots												
31	32	33	34	35	36	37	38	39	40	41	42	43
-b	-b	-b	-b	-c	-c	-c	-c	-a	-a	-a	-a	-b
c	c	c	a	a	a	a	b	b	b	c	c	c

Stator slots											Pole
44	45	46	47	48	49	50	51	52	53	54	
-b	-b	-c	-c	-c	-a	-a	-a	-b	-b	-b	p_1=5
a	a	a	b	b	b	b	c	c	c	c	

Table 2. An expanded scheme of DSSF winding p = 6 sides.

Stator slots															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
-e	-f	-f	-f	-d	-d	-d	-e	-e	-e	-f	-f	-f	-d	-d	-d
d	d	d	e	e	e	f	f	f	d	d	d	e	e	e	f

Stator slots													
17	18	19	20	21	22	23	24	25	26	27	28	29	30
-e	-e	-e	-f	-f	-f	-d	-d	-d	-e	-e	-e	-f	-f
f	f	d	d	d	e	e	e	f	f	f	d	d	d

Stator slots												
31	32	33	34	35	36	37	38	39	40	41	42	43
-f	-d	-d	-d	-e	-e	-e	-f	-f	-f	-d	-d	-d
e	e	e	f	f	f	d	d	d	e	e	e	f

Stator slots											Pole
44	45	46	47	48	49	50	51	52	53	54	
-e	-e	-e	-f	-f	-f	-d	-d	-d	-e	-e	p_1=6
f	f	d	d	d	e	e	e	f	f	f	

The combination of coil groups in the winding is carried out in accordance with the connections of coils in the basic scheme (BS) "YYY/YYY with additional branches".

When the lower row of each winding is located under each other (table 1 and table 2), by the name of the phase in the groove with one and the other winding, it is possible to determine the branch to which one or another coil number corresponds.

For example, groove No. 1 at p_1 = 5 of the pole winding corresponds to phase A, and at p_2 = 6 phase D, therefore, belongs to the branch D-A.

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 2, February 2025

The number of additional branches in each phase is generally n, but more often from one to three. The number of coils *i* in the additional branches of each phase can be even and odd. The construction of such windings is complicated by the need to eliminate equalizing currents in additional branches. When the winding is fed from the side of lesser pole, EMF is induced in the additional branches, which should be mutually compensated otherwise, surge currents appear. The absence of these currents is associated with fulfillment of the conditions [9,10]:

1. The vectors of the total electromotive force (EMF) of phase branches coincide in magnitude and direction when the winding is placed into a magnetic field with a large number of $2p_2$ poles;
2. The vectors of the total EMF of phase branches coincide in magnitude and direction when placing the winding into a magnetic field with a smaller number of poles $2p_1$ at n=3 and i=odd;
3. The EMF vectors of one branch coincide in magnitude and are directed in the opposite direction when the winding is placed into a magnetic field with a smaller number of $2p_1$ poles at $n=1\div Z$ and i=even;
4. The EMF vectors of one branch coincide in magnitude and lag behind by $2\pi/i$ electric degrees when placing the winding into a magnetic field with a smaller number of poles $2p_1$ for $n=1\div Z$ and $i\geq 3$.
Two conditions: the first and one of the others must be fulfilled simultaneously.

The fulfillment of condition 1 and 2 is possible with ratios p_1/p_2=1/2, 1/4, which, however, cannot be obtained for three-phase (on both sides) windings of the considered type.

According to conditions 1 and 3, the coil, which were carried into additional branches, must be simultaneously located at an even number of times τ_2 (diametral step) and an odd number of times τ_1, i.e. p_1 must be odd, p_2-even, and the number of grooves by which the coils are removed is divided by both τ_1 and τ_2. Most often, this number is $Z/2$.

Condition 1 and 4 are satisfied when the coils (or coil groups) of the phases of the same name carried in additional branches are at a distance equal to Z/i (most often $Z/3$), and p_1 can be odd, p_2-even, or vice versa.

In this case, the number of grooves per pole and phase q can be both integer and fractional.
We find the ratio of the coils for one and the other pole [4]:

$$\frac{p_1}{p_2}=\frac{5}{6}=\frac{Z_{p=5}}{Z_{p=6}}=\frac{45}{54} \qquad (1)$$

We find the number of coils in the additional branches of each phase:

$$\frac{Z1}{m}=\frac{Z_{p=6}-Z_{p=5}}{m}=\frac{54-45}{3}=3 \qquad (2)$$

In this case, according to condition 4, the mutual compensation of the EMF of the additional branches is carried out by connecting the coils of the additional branches in series and distributing around the circumference of the magnetic circuit with a lag of 120 electric degrees with respect to each other when placing the winding into a magnetic field with fewer poles. To do this, we place the bottom layer of each winding under each other (table 3) and exclude one coil from each phase of the pole zone from the pole $2p_1$. Accordingly, from the $2p_2$ pole side these can be coils in the grooves under the numbers: for phase D - 12, 30, 48; for phase E - 6, 24, 42; for phase F - 18, 36, 54 (in table 3 they are underlined below). These coils are displayed in additional branches and redistributing in phases, are involved in creating a magnetic field of $2p_2$ pole:

Table 3. Phase distribution in the lower layers of 5- and 6-pole windings.

Stator slots															Pole
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
a	a	a	b	b	0	b	c	c	c	a	0	a	a	b	p_1=5
d	d	d	e	e	e	f	f	f	d	d	d	e	e	e	p_2=6

Stator slots														Pole
16	17	18	19	20	21	22	23	24	25	26	27	28	29	
b	b	0	c	c	c	a	a	0	a	b	b	b	c	p_1=5
f	f	f	d	d	d	e	e	e	f	f	f	d	d	p_2=6

Stator slots														Pole
30	31	32	33	34	35	36	37	38	39	40	41	42	43	
0	c	c	a	a	a	0	b	b	b	c	c	0	c	p_1=5
d	e	e	e	f	f	f	d	d	d	e	e	e	f	p_2=6

Stator slots												Pole
43	44	45	46	47	48	49	50	51	52	53	54	
c	a	a	a	b	0	b	b	c	c	c	0	p_1=5
f	f	f	d	d	d	e	e	e	f	f	f	p_2=6

Define the numbers of coils in each branch of the winding, grouped in BS (table 4):

Table 4. Determining the number of coils in each branch of the winding grouped in BS.

№ coils	YYY/YYY BS branches with additional branches											
	D_{add}	D-A	D-B	D-C	E_{add}	E-A	E-B	E-C	F_{add}	F-A	F-B	F-C
	48, 12, 30	46, 1, 2, 3, 11	28, 37, 38, 39, 47	10, 19, 20, 21, 29	42, 6, 24	13, 14, 22, 23, 33	49, 50, 4, 5, 15	31, 32, 40, 41, 51	54, 18, 36	25, 34, 35, 44, 45	7, 16, 17, 26, 27	43, 52, 53, 8, 9

III. RESULTS AND DISCUSSING

The obtained PSW is symmetrical with respect to the power source from the $2p_2$ side of the pole, and from the $2p_1$ side there is a discrepancy in the total EMF vectors (Fig. 1.) between the branches of the same phase DA and D-B in amplitude by 6.2% and in phase by 6.9 el degrees, and accordingly, this leads to a difference in winding factors (Tables 5, 6).

Table 5. Winding data for the pole p_1=5

	Branches of BS «YYY/YYY with additional branches»								
	D-A	D-B	D-C	E-A	E-B	E-C	F-A	F-B	F-C
A	8,12	8,66	8,21	8,12	8,66	8,21	8,12	8,66	8,21
ξ	0,821	0,866	0,821	0,821	0,866	0,821	0,821	0,866	0,821
ϕ	20,8	27,7	11,1	140,8	147,7	131,1	260,8	267,7	251,1

Table 6. Winding data for the pole p_1=6

	Branches of BS «YYY/YYY with additional branches»								
	A-D	A-E	A-F	B-D	B-E	B-F	C-D	C-E	C-F
A	13,24	13,24	13,24	13,24	13,24	13,24	13,24	13,24	13,24
ξ	0,827	0,827	0,827	0,827	0,827	0,827	0,827	0,827	0,827
ϕ	61	301	179	61	301	179	61	301	179

Obviously, it is advisable to make the coils of the additional branches with a wire with a cross section three times larger (the current flows three times larger in these coils) and accordingly, with the number of turns three times smaller than in the other coils. In this case, almost complete coordination of magnetic inductions in the air gap will be achieved, the condition for which is the equality [11]:

$$\frac{w_5 \cdot \xi_5}{w_6 \cdot \xi_6} = \frac{p_1}{p_2} \qquad (3)$$

A slight difference in the magnitude of the magnetic induction may be due to the difference in the values of the winding factor.

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 2, February 2025

The winding factors of the pole-changing windings with $2p_1$ and $2p_2$ of the pole side are respectively ξ_5 = 0.833 and ξ_6 = 0.827.

An analysis of the harmonic composition showed that the most strongly expressed from the $2p_1$ = 10 side, in addition to the first harmonic, contains the 2nd, 3rd, 5th, 6th, 7th, 8th, 10th, 11th, 12th, 13th, 14th, 15th, 16th and 17th harmonic, on the $2p_2$ = 12 side, in addition to the first harmonic, contains the 2nd, 5th, 7th, 8- 10th, 11th, 11th, 13th, 14th, 16th and 17th harmonics, but taking into account the winding c factors, their influence is significantly reduced.

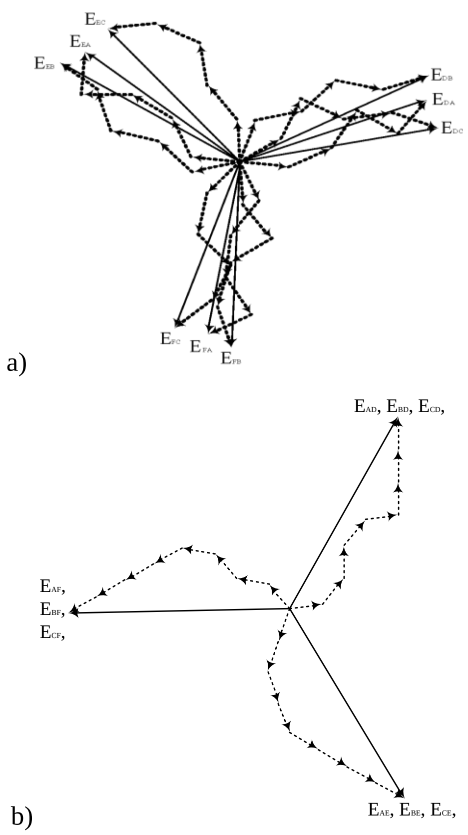

Fig. 1. EMF vector: a) 2p_1 = 10; b) 2p_2 = 12

Thus, the proposed PSW has improved MMF patterns, which leads to a decrease in the presence of higher harmonic and uniformly distributed circumference Gerges diagrams, which lead to a decrease in the differential leakage factors and additional losses, as well as to an improvement in vibroacoustic characteristics from both poles.

All of the above allows us to ensure the industrial applicability of the proposed software, since two-speed motors with such a winding can be used on numerous centrifugal pumps and fans, where it is necessary to adjust the rotation speed according to the technological process or in order to save energy.

The differential leakage factor σ_0 (in the air gap) is one of the criteria for evaluating the properties of a winding. The differential leakage factor is calculated on the basis of the Krondl theorem using the polygon of magnetomotive force (MMF) of Gerges.

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 2, February 2025

Differential leakage factor [12]

$$\sigma = \left(\frac{R_g^2}{R_1^2} - 1 \right) \cdot 100\% \qquad (4)$$

Fig 2. show Gerges diagrams for a PCW based on a YYY/YYY BS with additional branches for a 5/6 pole pair ratio with 54 stator slots and differential leakage factors.

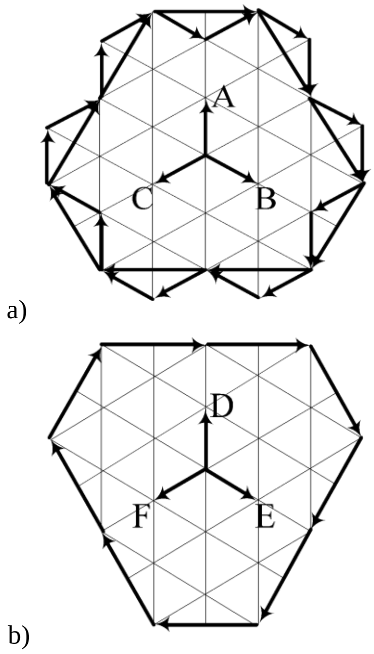

Fig. 2. Gerges PCW diagram according to the scheme "YYY/YYY with additional branches" at Z=54 and y=5: a) from the side p=5, σ=5,4%; b) from the side p=6, σ=11,3%

As can be seen from the analysis of electromagnetic properties at 54 stator slots on the side of both poles at step y = 5, the content of higher harmonics is minimal, and, accordingly, the value of the differential leakage factor is also minimal.

IV. CONSOLATION

Using the method of "DSSF", a new pole-changing winding was developed based on the basic scheme "YYY/YYY with additional branches" for a 5/6 pole ratio in the number of stator slots equal to 54.

The study and theoretical analysis of new characteristics of pole-changing winding have shown that this winding can completely be symmetrical in relation to source of power and will have high winding coefficient.

From a technological point of view, developed pole-changing winding shows itself like common two-layer winding, and this winding can be utilized in numerous centrifugal pupms and fans in where rotational speed regulation in technological processes or in whole energy saving is needed.

REFERENCES

[1]. 1. 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 (2018) https://dx.doi.org/10.25046/aj030424.
[2]. 2. M.Giet, K.Hameyer, S.Risse, Induction motor with pole-changing winding for variable supply frequency, 2007 IEEE International Electric Machines & Drives Conference, Turkey, 3-5 May 2007. DOI: 10.1109/IEMDC.2007.383647.
[3]. 3. Leonard Melcescu, M.V. Cistelecan, O. Craiu, H.B. Cosan. A new 4/6 pole-changing double layer winding for three phase electrical machines. The XIX International Conference on Electrical Machines - ICEM 2010, Italy, 6-8 Sept. 2010. DOI: 10.1109/ICELMACH.2010.5608041.

[4]. Karimov H.G., Tupoguz Y.A. A Method for Designing Electrically Aligned Windings in AC Machines. Journal “Elektrichestvo” -1987, Vol. 9, -pp. 29-38.
[5]. Kh.G. Karimov, M.K. Bobojanov, D.A. Rismuhamedov. Analysis of the construction and electromagnetic characteristics of the pole-changing winding. Bulletin of TSTU, -2004, No. 3, -pp 71-78.
[6]. Kh.G. Karimov, M.K.Bobojanov, D.A.Rismukhamedov, Improved Two – speeds motors for the Energy saving and Automation Problems // World Conference on Intelligent Systems for Industrial Automation (WCIS – 2000, Germany, Uzbekistan), 2000. -pp. 361-364.
[7]. Karimov Kh.G., Rismukhamedov D.A. Two – speeds induction motors for the energy saving measures // 6 th International conference on Engineering of Modern Electric Systems.- Oradea (Romania), 2001.- pp. 385-389.
[8]. D.A. Rismuhamedov, J.M. Mavlonov, F.N. Tuychiev, B.A. Markhabaev. Three-phase pole-changing winding with a ratio of poles 5/6. Uzbek patent IAP 05698, Bull. №11, issued 30 November 2018.
[9]. M.K. Bobojanov, D.A. Rismuhamedov, F.N. Tuychiev. Construction and analysis of a pole-changing winding for a 5/6 pole ratio using the DSSF method. Bulletin of TSTU, - 2016, No. 3-4, -pp. 138-143.
[10]. F.N. Tuychiev. Development of pole-changing winding for a 5/6 pole ratio at 108 stator slots using the DSSF method. Bulletin of TSTU, - 2017, No. 4, -pp. 58-63.
[11]. M.K. Bobojanov, D.A. Rismuhamedov, F.N. Tuychiev. Development of pole-changing winding for a 5/6 pole ratio at 108 stator slots using the DSSF method with additional branches. Bulletin of TSTU, - 2019, No. 1, -pp. 57-63.
[12]. Caruso M., Tommaso A., Marignetti F., Miceli R., G. Ricco Galluzzo. «A general procedure for the construction of Gorges polygons for multi-phase windings of electrical machines», in 2018 Thirteenth International Conference on Ecological Vehicles and Renewable Energies EVER, pp. 1-7, April 2018. https://www.researchgate.net/publication/325350240.