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Development of a pole-changing winding for three-speed motors

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Abstract. This article discusses the development of a pole-changing winding for multi-speed motors used in ventilation systems. Also, using the discrete spatial function method, it was analyzed that the induction ratio and the winding coefficient can be increased compared to the existing three-speed motor by developing a pole-changing winding with high electromagnetic properties with a pole ratio of 4:2 based on the basic "additional branch Y/YY" scheme.

INTRODUCTION

In the current "Y/YY" and "Δ/YY" basic circuits with pole changing windings, the ratio of magnetic inductions in the air gap (B2/B1) is significantly different from 1, which does not allow the full use of the active part of the electric motor. For example, elevators and lifting transport mechanisms use pulleys with a large pole ratio (1/4, 1/5, 1/6, etc.). To improve the air-gap magnetic induction matching of these motors, the "extra-branch Y/YY" basic winding scheme is used, and the extra branches are placed on the large pole side, i.e. on the $2p_1$ pole side [1, 2]. It is known that the power consumed by the electric drive of a fan varies cubically with the number of revolutions. Therefore, it is advisable to fully utilize the active part of the electric motor, especially the small pole. In these electric motors, it is advisable to introduce additional windings on the side of the small pole in order to equalize the magnetic induction distribution in the air gap and to increase the coercive force on the minor pole side. As a result, the ratio of magnetic inductions in the air gap (B_2/B_1) changes significantly and approaches unity, leading to a 20–30% increase in the output power corresponding to the small pole [3, 4]. We consider the development process of an electric motor of the rotating part of axial fans of the VO-06-300 type with a stator number of 36 slots. For this electric motor, the pole ratio $2p_1/2p_2$=8/4 (rotational speed 1500/750 rpm) and the existing one with a variable number of poles $2p_1$=6 (rotational speed 1000 rpm) are used.

EXPERIMENTAL RESEARCH

Building a pole-changing winding. Pole-changing winding schemes that are close to traditional circuits in terms of electromagnetic and technological properties can be obtained using the Discrete Specified Spatial Functions (DSSF) method [1, 5]. It differs from other methods in that the direction of the currents in some coils is reversed on one pole side [6]. This method is based on a new principle, and two simple double-layered surface-mounted coils with the number of pairs of poles p_1. and p_2, and the phases m_1. and m_2 are taken and used in the design of a two-speed coil at the same time. In this case, the winding connection scheme is not taken ready-made, but is formed during its construction process or is selected from previously known basic schemes, taking into account the distribution of phase currents along the motor's phases for each pole and the combination of the winding phases that are compatible with each other [6, 7].

The discrete elements of a conventional winding are the basic state of the electrical conductors in the stator slots of an electric motor and are divided into phases and supplied with a single conditional electrical conductor designated the same as this phase. For example, if the $2p_1$ pole winding (a, b and c) is a conditional conductor of positive unit current in the stator slots belonging to phases A, B and C, respectively, then the $2p_2$ pole winding (-d, -e and -f) is a conditional conductor of negative unit current belonging to phases D, E and F [8].

A switch with a variable number of poles is built not on simple circuits, but on special basic schemes (BS), which have several group outputs and are connected to the source in a certain sequence (Figure 1).

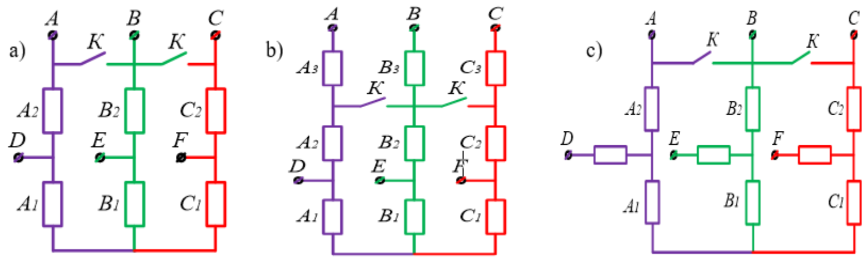

FIGURE 1. Basic schemes of a pole-changing winding: a) Y/YY; b) and c) Y/YY with additional branch.

After determining the required number of standard slots and the ratio of poles, the basic scheme is adopted and the construction of the PChW is carried out in the following order [9]:

1. The first row contains the DSSF of the first layer of the m-zone or 2m-zone circuit (initial circuit) corresponding to the large pole, that is, the ratio of the poles;
2. The second line is written as the DSSF of the first layer of the 2m-zoned grid (base grid) corresponding to the small pole, that is, the ratio of the poles;
3. If there are additional branches, their number is determined and the corresponding wedges in the third row are written with a zero value;
4. The position of the phase conductors of the first and second rows is compared, and the conductors corresponding to the minor pole of the modulated coil of the third row are written to the corresponding wedges.

Winding coupling. Therefore, the procedure for constructing the $2p_1$ pole part of a pole-changing winding is to sequentially consider the current states in each wedge, based on the rules given above, and write down the DSSF of the synthesized circuit (Table 1).

TABLE 1. Synthesis of a 2p1=8-pole winding

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	Slot
x	a	a	x	b	b	x	c	c	x	a	a	x	b	b	x	c	c	x	a	a	x	b	b	x	c	c	x	a	a	x	b	b	x	c	c	p1=4
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	f	f	-d	-d	-d	e	e	e	-f	-f	-f	p2=2
x	a	a	x	b	b	x	c	c	x	a	a	x	b	b	x	c	c	x	a	a	x	b	b	x	c	c	x	a	a	x	b	b	x	c	c	p1=4

The above synthesised winding is adapted to the basic scheme of the “extra branch Y/YY” winding [9] and the removed windings with the extra branch are replaced with (x). After that, the synthesized winding and the low pole side windings are combined (Table 2).

TABLE 2. DSSF of the lower layers, taking into account the exit of the windings to additional branches

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	Slot
x	a	a	x	b	b	x	c	c	x	a	a	x	b	b	x	c	c	x	a	a	x	b	b	x	c	c	x	a	a	x	b	b	x	c	c	p1=4
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	f	f	-d	-d	-d	e	e	e	-f	-f	-f	p2=2

It is worth noting that by correctly choosing the step at the $2p_1=8$ pole side, that is, at the main speed, it is possible to achieve very successful mutual matching of the layers and a shape close to a sinusoid of the magnetizing force lines. This Table 3 shows the DSSF of the upper and lower layers at a step of y=5 for a variable number of poles $2p_1=8$ poles [9, 10, 11].

TABLE 3. DSSF for $2p_1$=8 pole side

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	Slot
x	a	a	x	b	b	x	c	c	x	a	a	x	b	b	x	c	c	x	a	a	x	b	b	x	c	c	x	a	a	x	b	b	x	c	c	p1=4
-b	-b	x	-c	-c	x	-a	-a	x	-b	-b	x	-c	-c	x	-a	-a	x	-b	-b	x	-c	-c	x	-a	-a	x	-b	-b	x	-c	-c	x	-a	-a	x	p2=2

This Table 4 shows the upper and lower layer DSSF for a pole-changing winding $2p_2$=4 pole side with a pole pitch of y=5.

TABLE 4. DSSF for $2p_2$=4 pole side

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	Slot
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	f	f	-d	-d	-d	e	e	e	-f	-f	-f	p1=4
-e	-e	f	f	f	-d	-d	-d	x	-b	-b	x	-c	-c	x	-a	-a	x	-b	-b	x	-c	-c	x	-a	-a	x	-b	-b	x	-c	-c	x	-a	-a	x	p2=2

Using the phase combination table (Table 5) according to the obtained DSSF, it is possible to obtain a distribution table of windings along the branch and draw up a connection diagram for a pole-changing winding. A1, A2, A3 for the first phase, B1, B2, B3 for the second phase, C1, C2, C3 for the third phase. Table 2.8 shows the distribution of windings with a pole-changing windings along the branches of the switching circuit [12].

TABLE 5. Winding branches in the "Y/YY" scheme with additional branches

Neme of branch	Nomer of coil	Neme of branch	Nomer of coil	Neme of branch	Nomer of coil
A1	11, 12, 29, 30	*B1*	5, 6, 23, 24	*C1*	17, 18, 35, 36
A2	1, -10, 19, -28	*B2*	13, -4, 31, -22	*C2*	7, -16, 25, -34
A3	2, 3, 20, 21	*B3*	14, 15, 32, 33	*C3*	8, 9, 26, 27

Figure 2 shows an expanded electrical diagram of a three-phase pole-changing winding with a pole ratio of 8/4, in which the coil coils are grouped in an "additional branch star - double star" scheme. In this case, in part A1, the coils numbered 11-, 12-, 29-, 30- are connected in series, part A2 is divided into two, and in part A2.1, the coils numbered 1-, 10-, and in part A2.2, the coils numbered 19-, 28- are connected in parallel to each other, in part A3, the coils numbered 2-, 3-, 20-, 21- are connected in series, in part B1, the coils numbered 5-, 6-, 23-, 24- are connected in series, in part B2 is divided into two, and in part B2.1, the coils numbered 13-, 4-, and in part B2.2, the coils numbered 31-, 22- are connected in parallel to each other, in part B3, the coils numbered 14-, 15-, 32-, 33- are connected in parallel to each other. connected in series, in part C1, the coils numbered 17-, 18-, 35-, 36-, are connected in series, respectively, part C2 is divided into two parts: part C2.1, the coils numbered 7-, 16-, and part C2.2, the coils numbered 25-, 34-, are connected in parallel to each other, in part C3, the coils numbered 8-, 9-, 26- 27-, are connected in series, respectively [9, 13, 14].

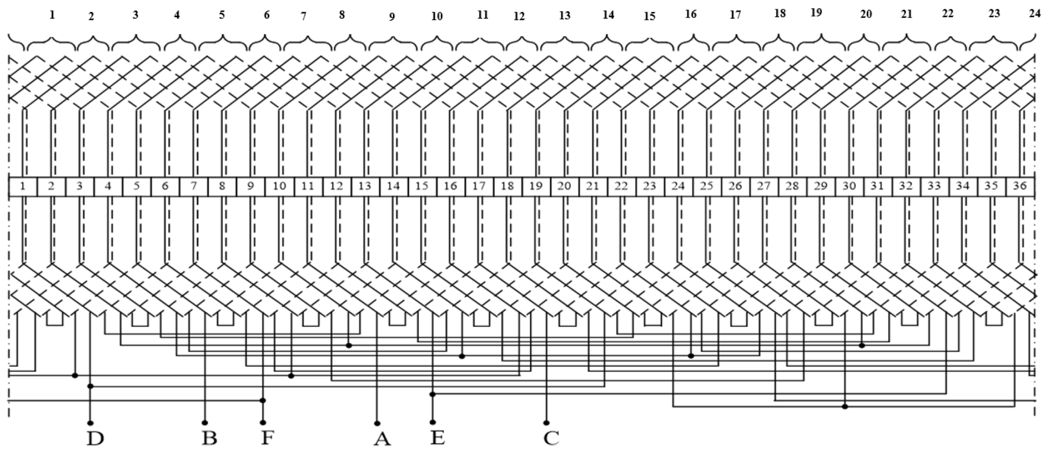

FIGURE 2. Extended electrical diagram of a PCHW with a pole ratio of 8/4

When a three-phase power supply is connected to the outputs A, B, C (in this case, outputs D, E, F are open, and the contactor contacts are disconnected), an eight-pole rotating magnetic wave is generated in the air gap. In the circuit, 24 coils are connected, the EMF vectors of each phase are equal in amplitude and rotated by 120° in phase, that is, they are completely symmetrical with respect to the power supply for the $2p_2$=8 pole side of the coil [15, 16].

Here, a proposed and extended electrical circuit based on the additional branched “Y/YY” BS with a stator slot number of 36, a pair pole ratio of 8/4 and a winding pitch of y=5 is presented. Output “A” is taken from the beginning of the 11th coil, output “B” is taken from the beginning of the 5th coil, output “C” is taken from the beginning of the 17th coil [9, 17, 18] and output “D” is taken from the connection point of the end of the 19th coil and the beginning of the 1st coil. The "E" output is removed from the connection point of the end of the 13th coil and the beginning of the 31st coil, and the "F" output is removed from the connection point of the end of the 7th coil and the beginning of the 25th coil. At the same time, the beginnings of the 21st-33rd-27th coils are connected to one common point [17]. To form a double star circuit, the winding must be equipped with a two-pole switch with two left and two right outputs.

First, the exact or multiple matching conditions between the PCHW and the BS branch current conductors developed on the basis of the BS are met, after which the PCHW scheme is obtained by making electrical connections of the current conductors in accordance with the BS branch connections [9].

RESEARCH RESULTS

When determining the electromagnetic properties of a pole-changing winding designed for a three-speed asynchronous motor [19], the optimal winding pitch, i.e., the winding pitch y=5, is used to determine the shape of the magnetic driving force lines for the pole sides with 2p=8, 2p=6, and 2p=4 (Figure 3).

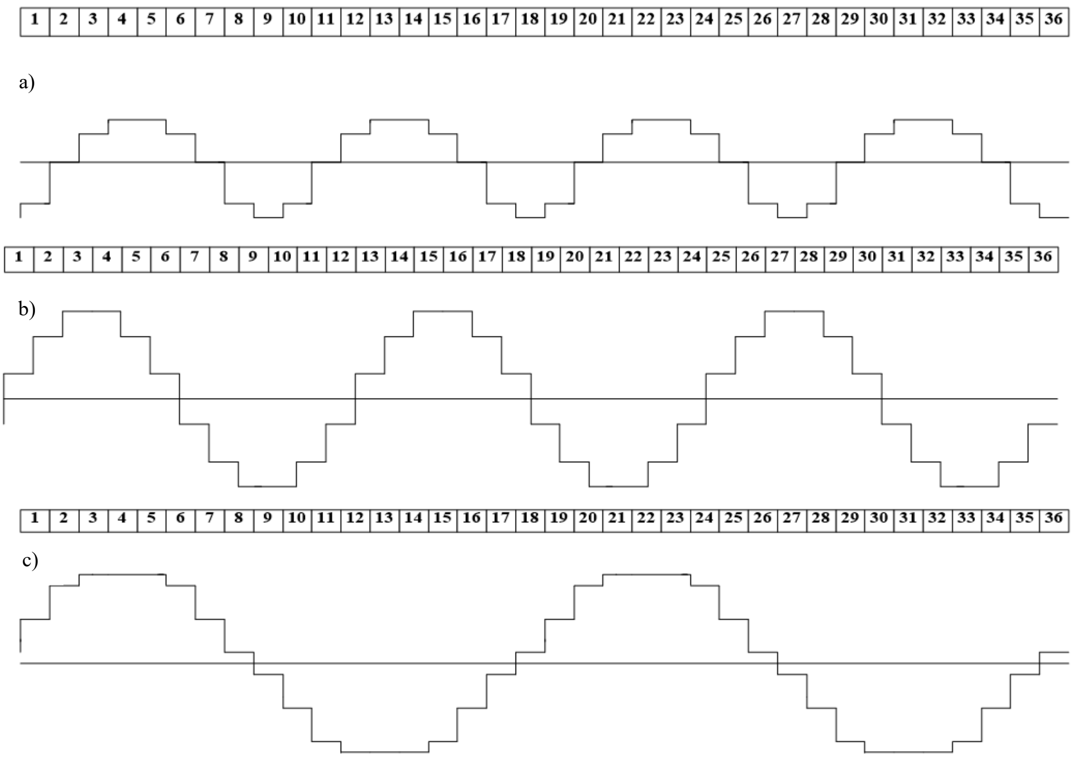

FIGURE 3. The shape of the magnetizing lines of force when the pulley step is y=5: a) 2p=8 direction b) 2p=6 direction c) 2p=4 direction

The results of the amplitude and the coefficient of the winding developed pole-changing winding for all three pole sides are presented in the following tables 6÷8. When the winding step is y=5, the coefficient of the windingl for the pole sides with 2p=8, 2p=6 and 2p=4 is k_{w1}=0.925, k_{w2}=0.933 and k_{w3}=0.735, respectively [9].

TABLE 6. p_1=4 for the pole side (y=5)

	"Y/YY" basic scheme branch								
	A1	*A2*	*A3*	*B1*	*B2*	*B3*	*C1*	*C2*	*C3*
A	14.81	14.81	14.81	14.81	14.81	14.81	14.81	14.81	14.81
K_{w1}	0.925	0.925	0.925	0.925	0.925	0.925	0.925	0.925	0.925
φ	70	170	50	70	170	50	70	170	50

TABLE 7. p_2=3 for the pole side (y=5)

	"Y/YY" basic scheme branch		
	A	*B*	*C*
A	22.39	22.39	22.39
K_{w2}	0.933	0.933	0.933
φ	0.00	120	120

TABLE 8. p_3=2 for the pole side (y=5)

	"Y/YY" bazaviy sxema shaxobchasi		
	D	*E*	*F*
A	8.82	8.82	8.82
K_{w3}	0.735	0,735	0,735
φ	20	140	100

When the step of the winding is y=5, the winding coefficient for the pole sides with 2p=8, 2p=6 and 2p=4 is $k_{w1}=0.925$, $k_{w2}=0.933$ and $k_{w3}=0.735$, respectively. As a result, it can be said that the induction ratio of this new pole-changing winding has been improved by 19.1% compared to the closest analogue.

CONCLUSIONS

Applying this newly developed pole-changing winding to electric machines will allow for more efficient use of the machine's active part, saving winding copper, saving insulating materials, and increasing energy performance. It also allows the weight and size of a multi-speed motor to be brought closer to that of a simple single-speed asynchronous motor. Using the Discrete Specified Spatial Functions method, a new pole-changing winding of 4:2 and high electromagnetic properties was developed based on the basic "additional branch Y/YY" scheme. As a result, the induction ratio of the new pole-changing winding has been improved by 19.1% compared to the closest analogue. Also, when determining the electromagnetic properties of this winding, the optimal winding step, i.e., the winding step y=5, the winding coefficient for the polar sides 2p=8, 2p=6, and 2p=4 will be k_{w1}=0.925, k_{w2}=0.933, and k_{w3}=0.735, respectively.

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