Development of two-speed asynchronous electric motors for the undercarriage of mine self-propelled cars

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Abstract. The paper presents a new double layer three phase 3/6 pole-changing winding, with 72 slots and 6 terminals with “Y/YY with additional branches” и “Y-Δ/YY” switching circuit. Using the discretely specified spatial function method, a two-speed asynchronous electric motor with a pole-switched winding was designed for self-propelled mine wagons, which were tested in static and dynamic modes of operation. The application areas of two-speed asynchronous motors with pole-switched windings are given. Currently, dynamic modes have not been investigated in the used two-speed engines. As the object of the study, a two-speed asynchronous motor of the AVTM - 6/12 brand of the self-propelled mine wagons drive was adopted in operating modes with no load on the shaft and when starting with a load of 500 Nm and switching to a second speed.

1 Introduction

At the mines of the Tyubegatan potash Deposit (Uzbekistan), wheeled self-propelled mine wagons (SPMW) are used to deliver the rock mass beaten off by a tunneling combine to ore outlets or directly to conveyor bunkers at distances of up to 200 meters [1]. In order to increase the efficiency of self-propelled mine wagons, it is necessary to regulate the speed of rotation of the engines, therefore, three-speed motors of the AVT15-4/6/12 type are used to drive them [2, 3].

The problem of creating pole-changing windings (PCW) for multi-speed electric motors was dealt with by many scientists from around the world [4, 5]. Series two-speed motors with a pole pair ratio of 1/2 have a pole-changing Dahlander winding in the stator [6, 7]. Pole changing method is one of the main methods of the speed control of an induction motor. The number of stator poles can be changed by pole amplitude modulation (PAM) method [8, 9] The method is used both for close ratio as well as for wide ratio [10]. Two-speed motors with pole ratio 2/3 and 3/4 are made with pole-changing windings obtained by the phase modulation method [11, 12].

To simplify the process of constructing a winding circuit, a new way of presenting the current distribution in the form of a discretely specified spatial function, in short, DSSF, was introduced, from which the method was called the "DSSF method" [13, 14].

The purpose of this article is to develop schemes of pole-changing windings and analyze a multi-speed electric motor on the drive of self-propelled mine wagons.

2 Pole changing winding method

The development of schemes for pole-changing windings with a close structure to normal windings, i.e. with improved electromagnetic properties is possible, using the modernized method discretely specified spatial function. The development of pole-changing windings in pole ratios $p_1/p_2=3/6$ based on basic circuits (BS) is peculiar, the use of asynchronous motors with a basic circuit of the type “Y/YY with additional branches” and “Y-Δ/YY” is appropriate. Including, on the drives of the undercarriage of mine self-propelled cars, when obtaining PCW based on schemes like “Y/YY with additional branches” and “Y-Δ/YY”, one has to synthesize a suitable one for one of the pluses of the DSSF [15].

As an example, consider the process of obtaining a PCW circuit for a pole ratio of $p_1/p_2=3/6$ with the number of slots $Z_1=72$. A normal m-zone winding with the number of poles $p_2=6$ was taken as the “initial” winding, and a normal 2m-zone winding with $p_1=3$ was taken as a "typical" one (Table 1).

Table 1. Synthesis of windings with pole $p_1=3$

1	2	3	4	5	6	7	8	9	10	11	12	13	Slots
a	a	a	a	$\underline{c}$	$\underline{c}$	$\underline{c}$	$\underline{c}$	b	b	b	b	$\underline{a}$	$p_1=3$ typical
a	a	a	a	c	c	c	c	b	b	b	b	a	$p_2=6$ initial
a	a	a	a	$\underline{c}$	$\underline{c}$	$\underline{c}$	$\underline{c}$	b	b	b	b	$\underline{a}$	$p_1=3$ synt.
14	15	16	17	18	19	20	21	22	23	24		72	Slots
$\underline{a}$	$\underline{a}$	$\underline{a}$	c	c	c	c	$\underline{b}$	$\underline{b}$	$\underline{b}$	$\underline{b}$	…	$\underline{b}$	$p_1=3$ typical
a	a	a	c	c	c	c	b	b	b	b	…	b	$p_2=6$ initial
$\underline{a}$	$\underline{a}$	$\underline{a}$	c	c	c	c	$\underline{b}$	$\underline{b}$	$\underline{b}$	$\underline{b}$		$\underline{b}$	$p_1=3$ synt.

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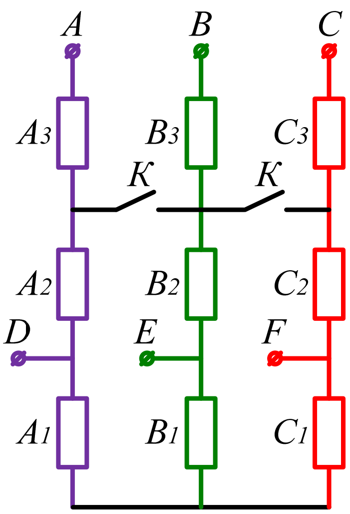
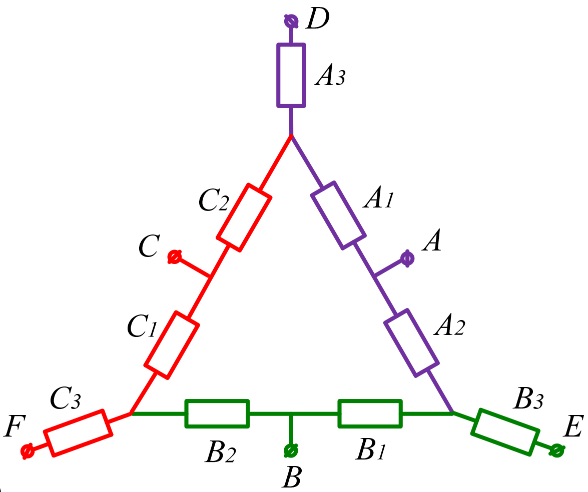
For example, if the position of the DSSF conductor in the original winding is equal to «b», and for a typical DSSF in the same phase as «a», which is known from the location of the three-phase system, currents that are close to «a» «-b», not «b» (direction of instantaneous currents corresponds), therefore, the synthesis winding is written «-b» for DSSF; if the DSSF of the original winding is «c», the DSSF of the typical winding is «-c», then «-c» is written in the DSSF of the synthetic winding [16].

The resulting windings on both sides of the poles are absolutely symmetrical with respect to the power source, the EMF vectors of the same branches of each phase are symmetrical with respect to each other, that is, they are equal in amplitude and rotated in phase by an angle of 2π/3 el.rad. For the basic circuit “Y-Δ/YY” with a winding step y=6 on the side of the poles $2p_1$ and $2p_2$, the winding factors are equal to k_{w1}=0.691 and k_{w2}=0.717, respectively, and for the basic circuit “Y/YY with additional branches” it is equal to k_{w1}= 0.757 and k_{w2}=0.88.



a)

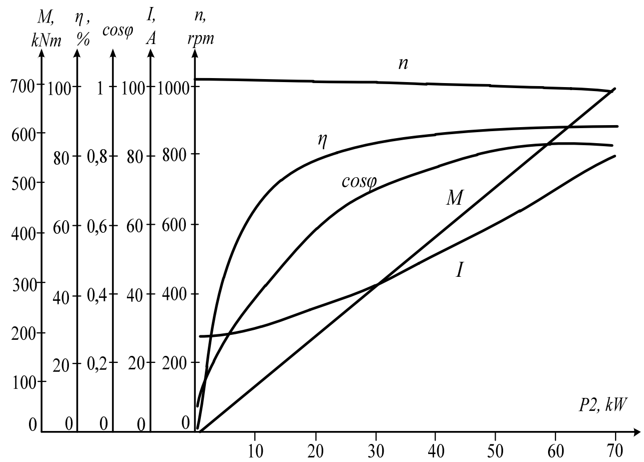


b)

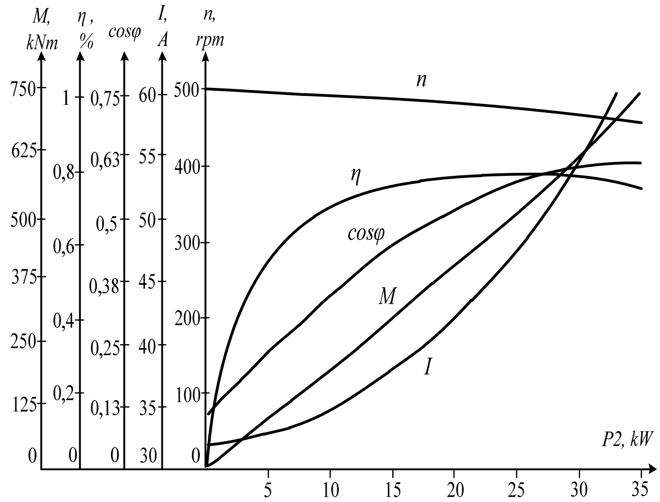
Fig.1. Scheme of switching for PCW:
a) “Y/YY with additional branches”; b) “Y-Δ/YY”

3 Results and discussion

For experimental confirmation of theoretical studies, prototypes of pole-changing two-speed electric motors of the AVTM15-6/12 type were manufactured, which were tested in static and dynamic modes of operation as part of the electric drive of the corresponding mechanisms. The results of experimental studies have shown that for the pole p_1=3, the useful power P_2=55 kW, efficiency η=87.5%, power factor cosφ=0.83, with stator current I_1=65 A and rotor speed n=973 rpm, for the pole p_2=6, the useful power P_2=26 kW, efficiency η=80%, power factor cosφ=0.59, with stator current I_1=48.8 A and rotor speed n=474 rpm were obtained (Fig.2).



a)



b)

Fig.2. Performance curves of the motor AVTM -6/12:
a) for p_1=3; b) for p_2=6

A common disadvantage of a two-speed asynchronous motor with a squirrel-cage rotor is an additional shock torque, which creates large mechanical stresses and shocks in gears during start-up and switching from one speed to another.

Experimental tests were carried out to study the operation of a newly developed electric motor for self-propelled mine wagons in a pole-changing mode and a curve was obtained for changing the stator current, speed, torque and voltage of a two-speed motor of self-propelled mine wagons when a load of 500 Nm was applied to the shaft.

As an object of research, the operating modes of operation during start-up and when switching to the second speed of a two-speed asynchronous motor AVTM-6/12 in electric drives of the undercarriage of self-propelled mine wagons are studied.

Initially, transient processes were studied and curves were obtained as a function of time, changes in stator current and torque during 6- and 12-pole starts. Figures 1 and 2 show the change curves of the above parameters (I=f(t), M=f(t)).

From these curves it can be seen that the steady state of the engine is very fast, i.e. after 320 ms for $p_1=3$, after 420 ms for $p_2=6$.

As can be seen from the curve in Figure 1, the amplitude value of the starting current of the electric motor is 650 A, the output to the steady state operation of the motor occurs after 0.5 s, and the amplitude value of the steady current is 85 A. The rated motor speed is 974 rpm, the rated motor torque is 450 Nm, and the maximum torque is 2 kNm.

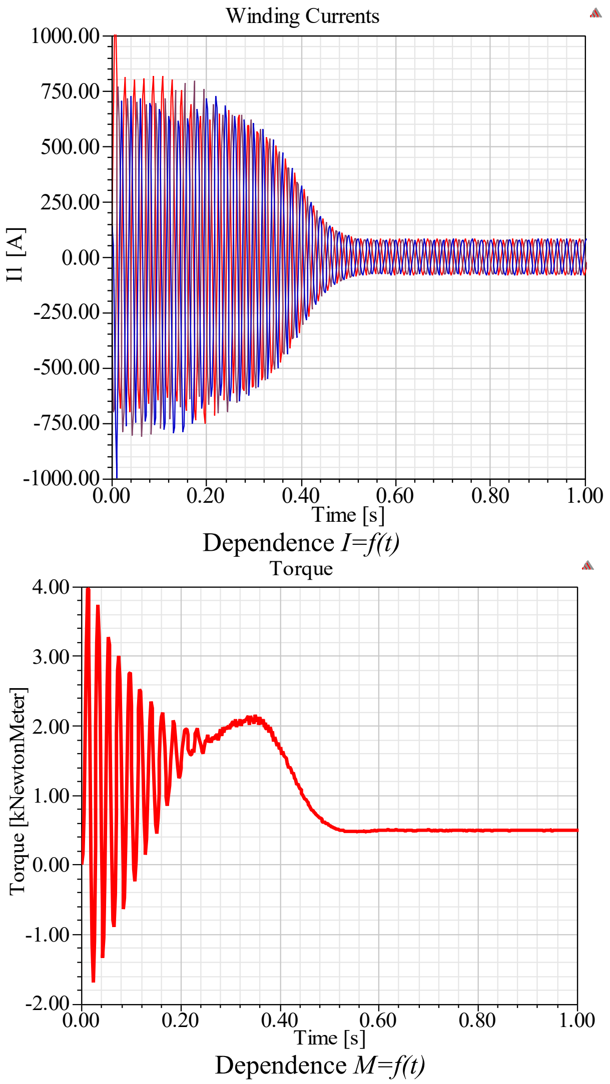


Fig.3. AVTM–6/12 electric motor start from $p_1=3$

As can be seen from the curve in Fig. 4, the amplitude value of the starting current of the electric motor is 210 A, the output to the steady state operation of the engine occurs after 0.75 s, and the amplitude value of the steady current is 60 A. The rated motor speed is 480 rpm, the rated motor torque is 500 Nm, the maximum torque is 1 kNm.

In the case of changing the speed of two-speed variable-pole induction motors from high to low, that is, the self-propelled mine wagons moves along the main underground freight road at a speed of 1000 rpm, when loading or unloading the transition to a speed of 500 rpm, a curve of change in time, motor current (I=f(t)), torque (M=f(t)).

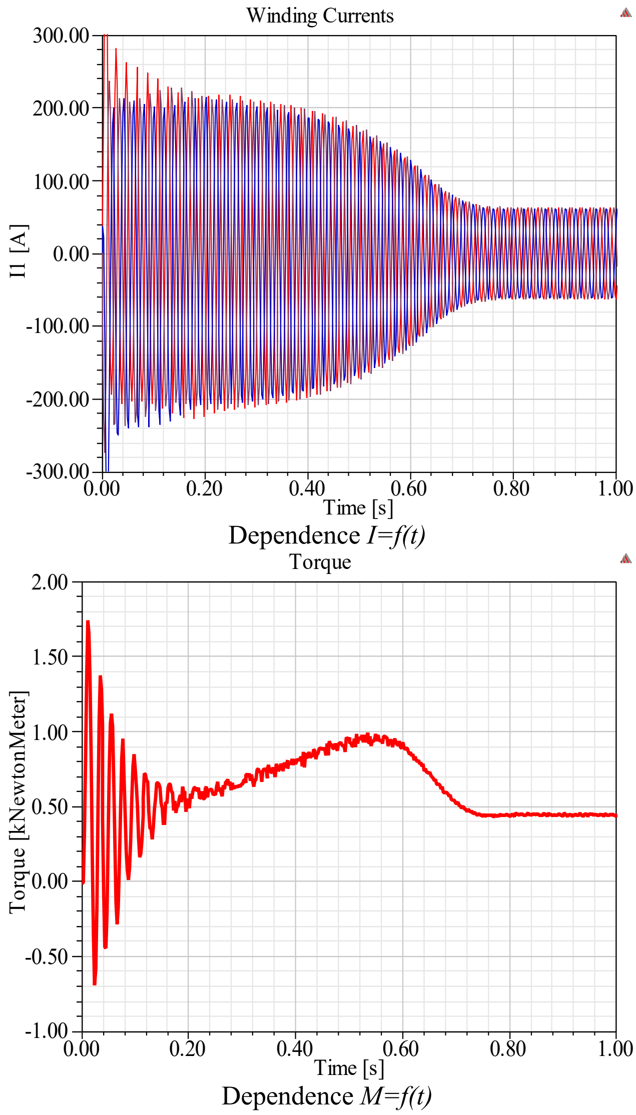


Fig.4. AVTM–6/12 electric motor start from $p_2=6$.

As can be seen from the curve in Fig. 5, the amplitude value of the starting current of the electric motor is 230 A, the output to the steady state operation of the engine occurs after 0.3 s, and the amplitude value of the direct current is 62 A. The rated engine speed is reduced from 970 rpm to 480 rpm. The motor is in braking mode, the maximum braking torque is 1.15 kN,

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then the maximum torque is 0.66 kNm, the rated torque is 450 Nm.

In the case of a change in the speed of two-speed asynchronous motors with a variable number of poles from high to low, that is, a mine car moved during loading or unloading at a speed of 500 rpm, along the main underground freight road of the transition to a speed of 1000 rpm, a curve of change in time, motor current (I=f(t)), torque (M=f(t)).

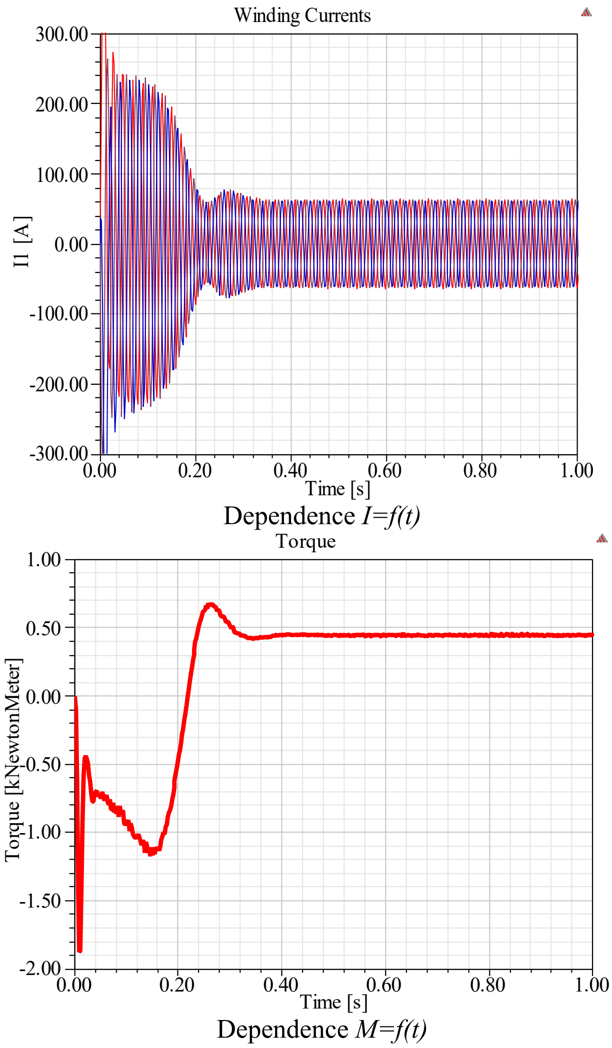

Fig.5. Switching motor poles ABTM -6/12 from p_1=3 to p_2=6 at a load of 500 Nm

As can be seen from the curve in Fig. 6, the amplitude value of the starting current of the motor is 500 A, the output to the steady state operation of the motor occurs after 0.3 s, the amplitude value of the steady current is 80 A. The rated engine speed has increased from 480 rpm to 970 rpm. The rated torque of the motor is 500 Nm and also, the maximum torque is 2 kNm.

From all the results of studies of the dynamic mode of operation of an electric drive with an AVTM15-6/12 motor, it can be concluded that the transition time of the start-up process, the transition from one speed to another, the level of noise and vibration in the engine were in all cases within the allowable range.

This means that electric drives based on new variable pole asynchronous motors can indeed be created and applied to self-propelled mine wagons operated in underground mines, and as a result, the rational use of electricity and natural resources is ensured.

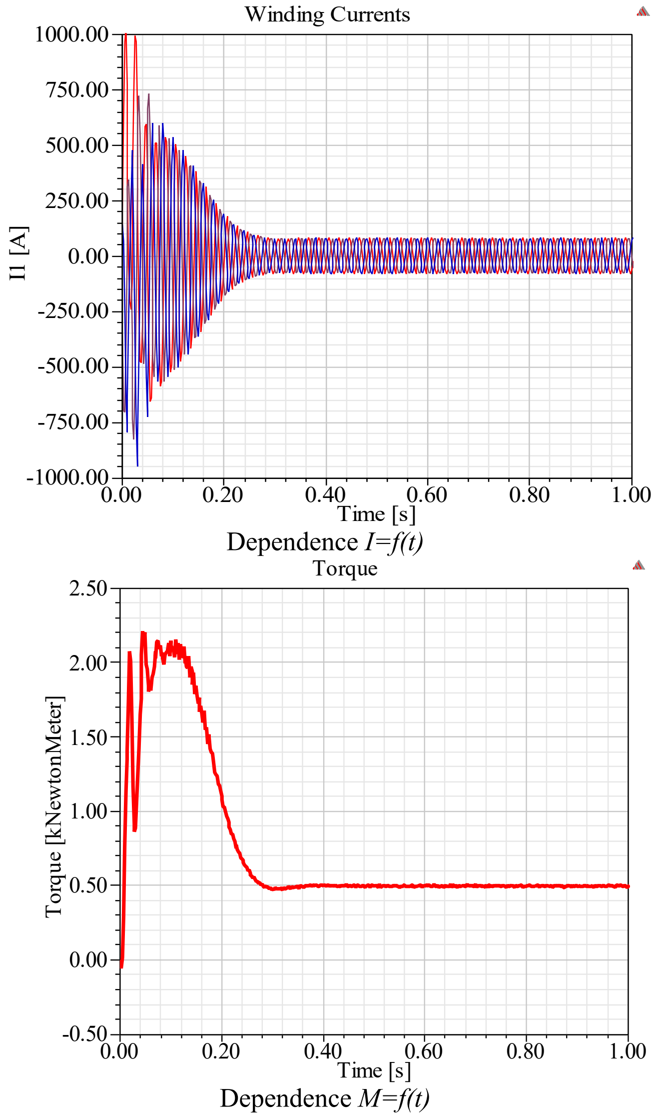

Fig.6. Switching motor poles ABTM -6/12 from p_2=6 to p_1=3 at a load of 500 Nm

Thus, the experiment carried out on self-propelled mine wagons operating in the harsh conditions of potash mines showed that the electric drives of the undercarriage of a mine self-propelled car based on a two-speed asynchronous motor with a variable number of poles satisfy all basic requirements.

4 Conclusions

As the results of the analysis showed, the new pole switching winding scheme has electromagnetic properties that are as close as possible to traditional two-layer windings.

Using the DSSF method, a new circuit of a pole-switched winding for a pole ratio of 3/6 with a switching circuit "Y/YY with additional branches" and "Y-Δ/YY" with a number of stator slots equal to 72 has been developed, for which a patent for the invention has been received.

The new pole switching winding was tested on an asynchronous motor built on the basis of the AVTM-6/12 motor, developing a rated power of 55 kW/26 kW for 3/6 poles, respectively.

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