Experimental Study of the Fan Electric Drive Based on Two-Speed Motor with Pole-Changing Winding

M. Bobojanov, D. Rismukhamedov, F. Tuychiev, Kh. Shamsutdinov

***Abstract*—**The article presents the results of experimental study of a two-speed asynchronous motor 4A80B6/4U3 with pole-changing winding on a fan drive VSUN 160x74-0.55-4 in static and dynamic modes. A prototype of a pole-changing Motor was made based on the results of the calculation and the performance and mechanical characteristics of the Motor were removed at the experimental stand, and useful capacities and other parameters from both poles were determined. In dynamic mode, the curves of changes of torque and current of the stator were removed by direct start, constant speed operation, by switching of speeds and stopping.

***Keywords*—**Pole-changing winding, two speed asynchronous machine, basic scheme, winding factor, differential leakage factor.

I. Introduction

Recently, the issue of studying the electric drive of fan installations based on two-speed asynchronous motors under various operating modes has become relevant. These modes include direct start, changing of speed, braking, etc. [1]-[3].

In connection with the use of controlled electric drives in mechanisms with a fan load torque based on two-speed motors with a squirrel-cage rotor, the issues of the behavior of motors during direct or stepped starting and switching of speeds are of great interest. Special interest is the study of the operation of an electric drive based on a two-speed asynchronous motor with one pole-changing winding on the stator instead of two separate windings. Undoubtedly, the second kind of construction has a lot of advantages in view of the smaller slot area which is occupied with one winding. This allows to use the active part of the electric machine more efficiently, increase energy parameters, simplify manufacturing and repair technologies [4]-[6].

II. Development and Test of Two-Speed Induction Motor

At the Tashkent State Technical University for experimental study in various operating modes of work was developed a two-speed asynchronous motor with a pole-changing winding with a pole ratio of 2:3 [2].

The design of a two-speed Motor with pole-changing winding was made on a magnetic core of a common 4-pole squirrel-cage motor Motor 4A80B4U3 with an output power of 1.5 kW and a nominal speed of 1475 rpm.

Table I shows the main parameters of magnetic core of the Asynchronous Motor 4A80B4U3.

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TABLE I
Main Parameters of Magnetic Core of the Asynchronous Motor 4A80B4U3

Parameters	Value
Stator outer diameter, mm	131
Stator inner diameter, mm	84
Number of slots on the stator	36
Rotor outer diameter, mm	83.5
Rotor inner diameter, mm	22
Number of slots on the rotor	28
Length of the stator package, mm	98

At first a prototype of a pole-changing motor 4A80B6/4U3 with a squirrel cage rotor was tested in static modes and performance characteristics were removed. Figs. 1 and 2 show the performance characteristics of the Motor 4A80B6/4U3 based on the results of experimental researches.

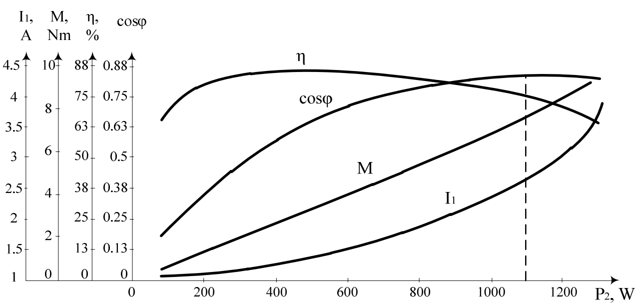


Fig. 1 Performance characteristics of the Motor 4A80B6/4U3 from p_1 = 2 poles

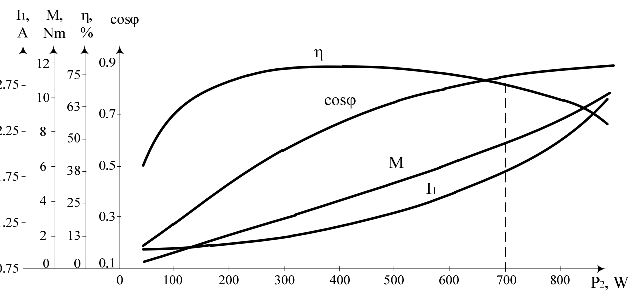


Fig. 2 Performance characteristics of the Motor 4A80B6/4U3 from p_2 = 3 poles

As experimental research of the Motor 4A80B4/6U3 has shown, from the side of p_1 = 2 pairs of poles, the useful power reaches the value of 1100 Watt, efficiency and cosφ corresponding to this power amount to 75% and 0.83, the nominal stator current is equal to 2.7 A.

For 6 poles, the value of useful power of the two-speed motor reaches 700 Watt, the values for efficiency and power factor to this power are equal 71% and 0.87, the nominal stator current - 1.7 A.

Fig. 3 presents motor speed-torque characteristics of a two-speed Asynchronous Motor 4A80B4/6U3 with a pole-changing winding. As can be seen from Fig. 3, the speed-torque characteristics are smooth, the starting torque from the $2p_1 = 4$ poles side is 7.1 Nm, and from the $2p_2 = 6$ poles side - 4.6 Nm. The value of the maximum starting torque from the side $2p_1 = 4$ poles is 12.5 Nm, and from the side $2p_2 = 6$ poles 9.5 Nm.

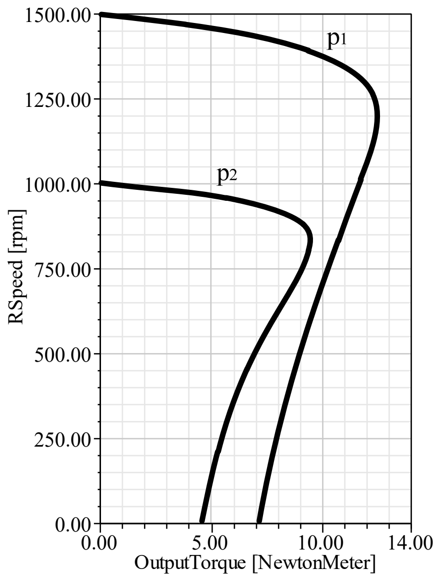


Fig. 3 Motor speed-torque characteristics of a two-speed motor

III. Experimental Research of Motor in Dynamic Mode

To study the operating modes, an electric fan drive VSUN 160x74-0.55-4 with a pole changing Motor 4A80B6/4U3 was tested in dynamic modes:

a) direct start;
b) working with constant speed;
c) switching of speeds and stopping.

In the drive systems, depending on the mechanical load, the motor may be subjected to variable operating conditions in its duty cycles. The electric motor in a fan drive can operate in various conditions such as starting, accelerating, steady-state, decelerating and stopping.

Generally, the basic equation of motion of motor driving a load, is given by:

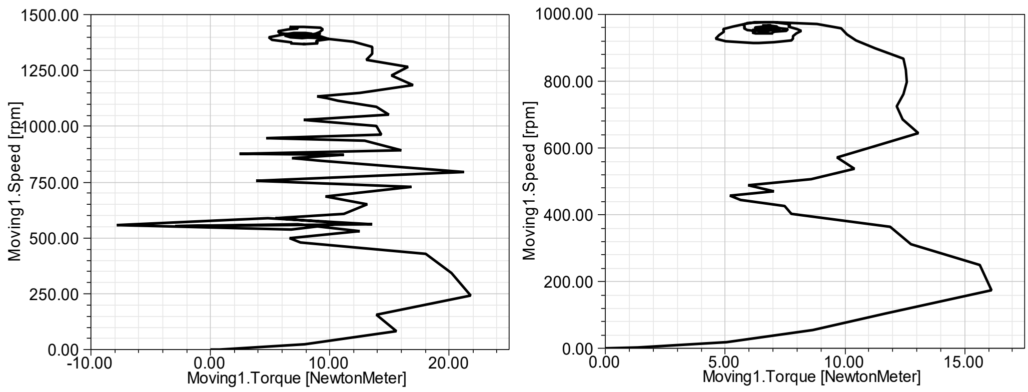
$$T_M - T_L = J\frac{d\omega}{dt} \quad (1)$$

where T_M: instantaneous value of developed motor torque, Nm; T_L: instantaneous value of load torque, referred to the motor shaft, Nm; J: moment of inertia of motor load system referred to the motor shaft, kg·m^2; ω: instantaneous value of angular velocity of motor shaft, rad/s; $J\frac{d\omega}{dt}$: torque component called dynamic torque because it is present only during the transient operations.

Depending on the ratio between the moments T_M and T_L, the following modes of operation of the electric drive are possible:

- when $T_M > T_L$, i.e. the dynamic torque $\frac{d\omega}{dt} > 0$, the drive is accelerating.
- when $T_M < T_L$, i.e. the dynamic torque $\frac{d\omega}{dt} < 0$, the drive is decelerating and coming to rest.
- when $T_M = T_L$, i.e. $\frac{d\omega}{dt} = 0$, the drive continues to run at same speed if it was running.

To determine the starting torques, a two-speed motor with a shaft load was simulated using the Program Ansys Maxwell.



(a) (b)

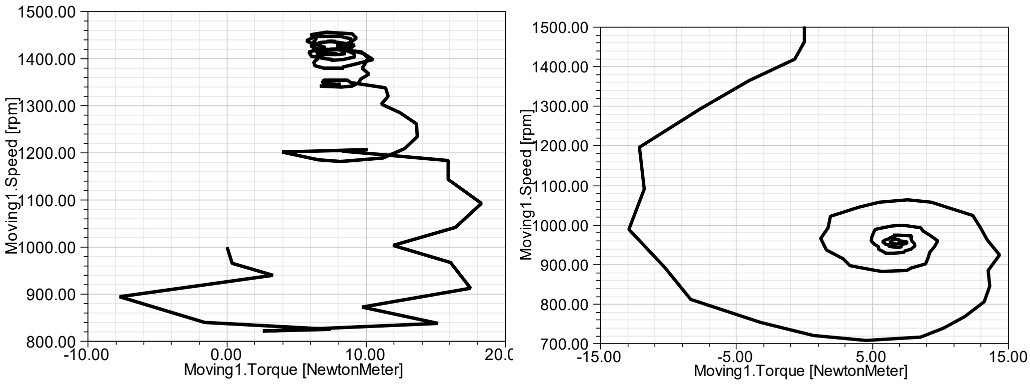
Fig. 4 Characteristics of starting torques for direct starting

Fig. 4 presents the characteristics of the starting torques for direct starting from $p_1 = 2$ (a) and from $p_2 = 3$ (b) poles. As can be seen from the obtained curves, the maximum starting torque of the Motor on the $p_1 = 2$ side reaches 22 Nm and on the $p_2 = 3$ side it reaches 16 Nm.

Using of a stepped start, the overclocked mechanism at the first speed has a lower moment of resistance M_r than with a direct start, therefore, to maintain a constant excess torque M_{et}, a smaller electromagnetic torque of the motor M is required, as well as a lower starting current ratio. Also, a decrease in the starting current ratio is observed during self-starting of electric motors, which ensures the continuity of the technological process, in which motors that have reduced their angular velocity during a short circuit in the network or during switching to a backup power source are not turned off by protection, and when the voltage is restored quickly reach normal angular velocity [7]-[9].

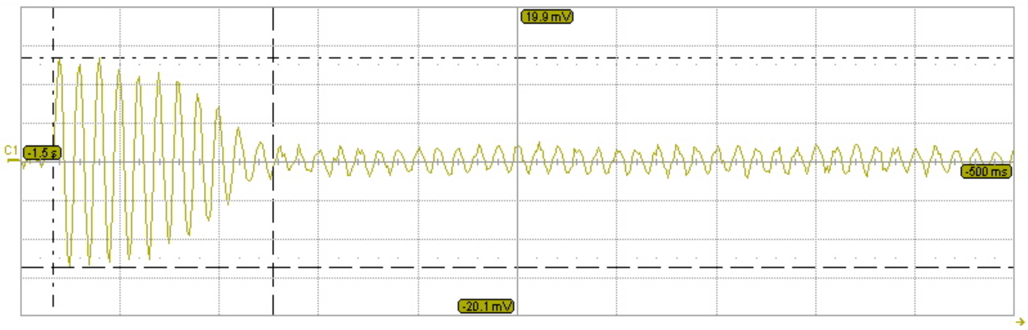
Fig. 5 shows the characteristics of the moments by switching the Motor 4A80B6/4U3 from low speed to high (a) and from high speed to low (b). As can be seen from the obtained curves, by starting of the Motor in steps (when switching from low to high speed), the Motor torque decreases to 18 Nm, and when decelerating (when switching from high to low speed), the Motor torque also decreases to 14 Nm, which indicates the absence of mechanical shock.

To study transient modes of Motor in the research laboratory of the Department Electrical Energy Supply of Tashkent State Technical University, the operation of an electric fan drive of the VSUN 160x74-0.55-4 type with a two-speed motor 4A80B6/4U3 was tested during direct and stepped start, operation at a constant speed, switching to the second speed (deceleration) and stop [7], [9].

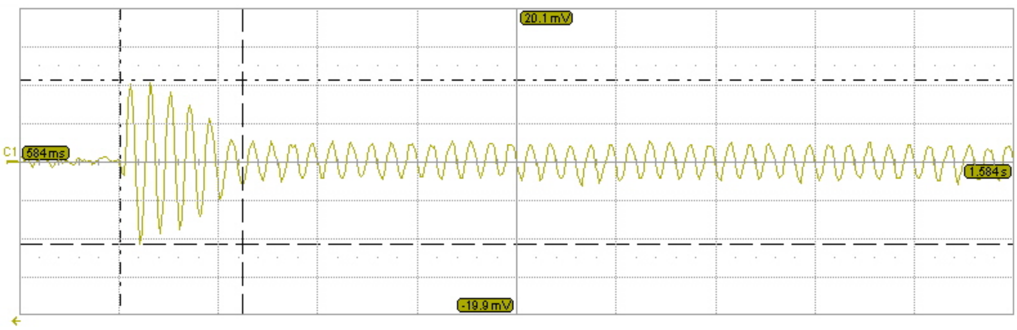


(a) (b)

Fig. 5 Characteristics of moments by speeds switching of a two-speed motor

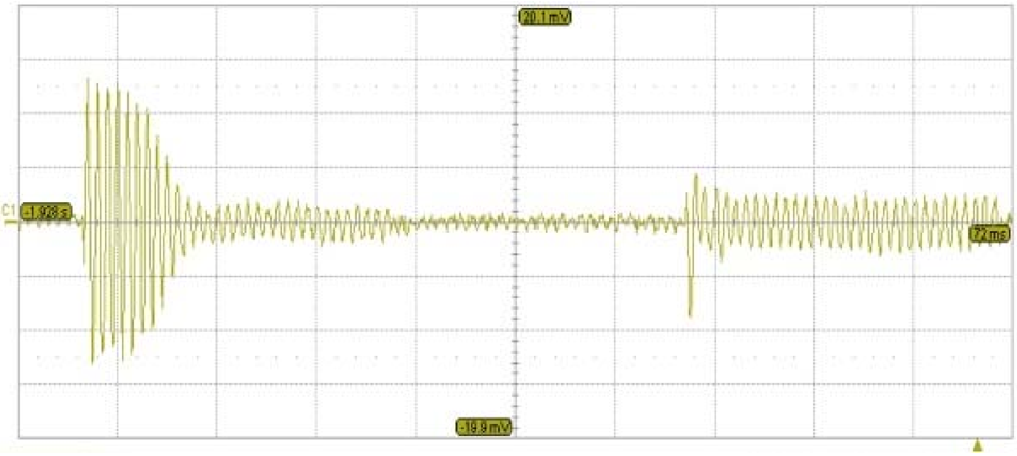


(a)

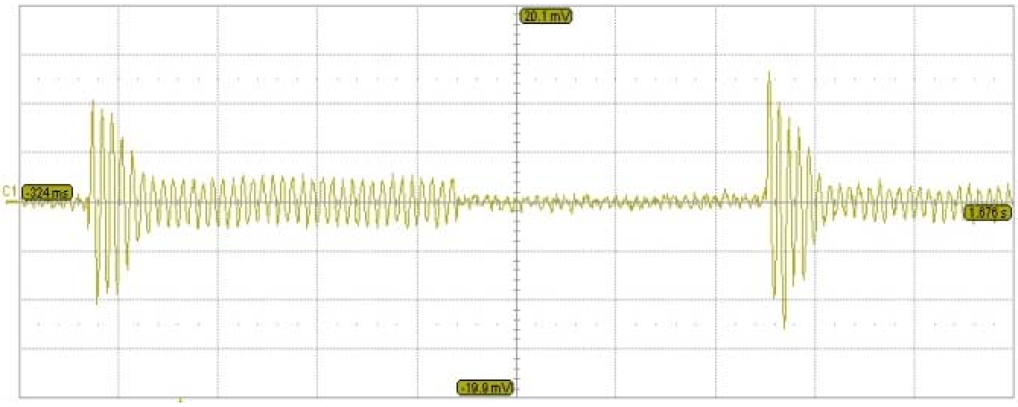


(b)

Fig. 6 Stator current change curve at direct start



(a)



(b)

Fig. 7 Curve of change of stator currents by switching of the Motor 4A80B6/4U3

Fig. 6 (a) shows the curve of the stator current change depending on the time during start from the state of the rest by $p_1 = 2$ side. As can be seen from this curve, the onset of the steady state operation of the motor occurs in 211 ms, the value of starting current is -13.53 A. Fig. 6 (b) shows the curve of the stator current change depending on time by starting from a state of rest by the $p_2 = 3$ side. Here the onset of the steady state operation of the motor occurs in 124 ms, the value of starting current is 10.87 A.

When switching directly from high to low speed, large dynamic torques occur in the motor, which are much higher than the rated torque and can exceed the critical torques in motor mode.

Fig. 7 (a) presents the curve of the stator current change depending on time when starting from a standstill state by $p_1 = 2$ and switching a two-speed motor to $p_2 = 3$ poles. As can be seen from this curve, the onset of the steady state of the motor occurs within 0.2 s, the value of starting current is - 13.53 A. After 0.6 s after the steady state operation on the $p_1 = 2$ side, the electric motor was switched to $p_2 = 3$ poles. Here the steady state of the motor operation occurs in 0.06-0.07 s, with a short-term starting current of 8.45 A [9].

Fig. 7 (b) shows the curve of the stator current change depending on time when starting from a standstill state by $p_2 = 3$ and switching a two-speed motor to $p_1 = 2$ poles. As can be seen from this curve, the onset of the steady state operation of the motor occurs within 0.1 s, the starting current is 10.87 A. After 0.6 s work in the steady state operation on the $p_2 = 3$ side, the electric motor was switched to $p_1 = 2$ poles. In this case (Fig. 7 (b)), the steady-state operation of the motor sets in within 0.1 s, the starting current is 11.85 A less than with direct start [3].

Analyzing the above transient curves, one can say that the functioning of a new electric drive based on a two-speed pole-changing asynchronous motor with a close speed ratio in dynamic modes is similar to the operation of an electric drive based on a conventional single-speed asynchronous motor.

The time of the starting, switching from one speed to another, self-starting and braking under load are within acceptable limits.

IV. Recommendation for Use

Based on the results of the conducted research, the following recommendations can be formulated for companies that have asynchronous motors operating with variable load in shaft [2] and [6]:

1. On the drives of mechanisms with a fan load at industry

and in pumping plants, instead of common single-speed motors operating for a certain time in underloaded mode, it is possible to install pole-changing two-speed motors and achieve energy and resource savings by using of the second speed.

2. At the pumping stations with several pumping units, the total capacity of the pumping station can be regulated comprehensively by switching the electric motors of some pumping units to a second speed to achieve the required productivity of the pump station as a whole.
3. For installations with heavy start conditions, it is also recommended to use two-speed motors with pole-changing windings to make step-by-step start and stop of these installations.

V. Conclusions

Summarizing the results of theoretical and experimental studies on the development of a new two-speed motor with pole-changing winding for driving of fan installations, the following can be drawn:

1. By the introduction of two-speed motors with pole-changing windings to drive of mechanisms with a fan type of load instead of single-speed motors, a significant economic effect is achieved by saving of electrical energy in low-load modes, it facilitates the start and stop of powerful motors;
2. Due to the use of one pole-changing winding instead of two separate windings, savings of winding copper and insulating materials are achieved, the active part of the magnetic core is used more rationally.

References

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