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The tape winding current impact on the motor's torque curve

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Abstract. The paper presents numerical simulations of the tape winding current impact on the motor's torque curve. The tape winding is a novel type of a motor's stator organization, allowing the large current flowing through the winding. Consequently the main flux of the permanent magnets changes. The estimation method of the developed torque dependence over the rotor and stator angular position is shown. Taking into account the control current effect the dependence is deformed, in particular it rotates relatively to the center.

1 Introduction

The torque curve is one of the main characteristics of the permanent-magnet torque motor. This curve shows the developed torque dependence from the current in the control winding. Generally, the torque curve is linear, without the demagnetizing effect of the winding current. It is possible with the rare earth magnets system. This statement relates to the torque motors, which are widely used in the modern devices [1-4]. However, the value of the control current in the tape winding torque motor [5] affects on the torque curve. It can be explained by the motor design, where the large current flowing is possible through the tape winding. This current generates the magnetic flux, which disfiguring the main flux of the motor.

Other important characteristics of the torque motor is the developed torque dependence over the rotor and stator angular position. This dependence allows to evaluate torque's pulsations during the rotor movement. The dependence can be determined considering the set of the torque curves over the different stator and rotor positions. In this set, the main motor's magnetic flux has the non-uniform deformation.

The purpose of this paper is to define the character of the torque curve distortion and to evaluate the changes of the developed torque from the control current.

In [6] it is shown that the torque of the tape winding motor is given by the expression

$$T = B_{\delta} \cdot \frac{r_{av} \cdot \Delta}{I_0} \cdot \frac{U}{R} \cdot D(x, y, I_0). \tag{1}$$

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Previously [6] assumed that flux density B_δ is the constant value in all subdomains, where the double integration is carried out. This is appropriate for the limited winding current $I = \frac{U}{R}$. However, at large currents the flux density depends on current $B_\delta(I)$.

Referring to (1), let us believe that the character of current lines distribution in the winding layers is independent from the flux density and current value: $D(x, y, I_0) = const$. Besides, the geometric parameters are also considered as stable: $\delta = const$, $r_{av} = const$, and $\Delta = const$. Under these conditions (1) can be written as

$$T = k \cdot I \cdot B_\delta(I), \tag{2}$$

where $k = \frac{r_{av} \cdot \Delta}{I_0} \cdot D(x, y, I_0) = const.$

The equation (2) shows that the motor's torque is proportional to the winding current and depend on flux density in the air gap. And the flux density is the function of the current. Furthermore (2) can be written as

$$T = k_2 \cdot I \cdot \sum_{i=1, j=1}^{m,n} \left[D(x, y, I_0) \cdot B_\delta(I) \right]_{ij}, \tag{3}$$

where $k_2 = \frac{r_{av} \cdot \Delta}{I_0} = const.$

If the pole flux density is non-uniform, in particular distorted by the tape winding current, it is necessary to divide the tape surface under the pole on $(m \cdot n)$ certain subdomains. Each ij of these subdomains has the constant flux density, equal to the average value $(B_\delta)_{ij}$ for this subdomain. The double integral value $[D(x, y, I_0)]_{ij}$ should also be defined for that subdomain. This is shown in equation (3).

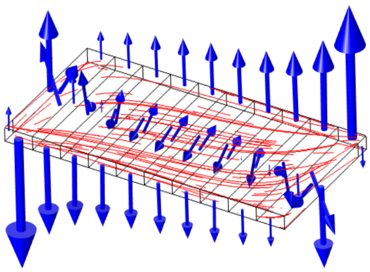
Further, the torque curve corresponding to the specified pole position over the tape winding pack can be defined as the dependence at the discrete current values

$$[F(I)]_x = \frac{T}{I} = k_2 \cdot \sum_{i=1, j=1}^{m,n} \left[D(x, y, I_0) \cdot B_\delta(I) \right]_{ij}. \tag{4}$$

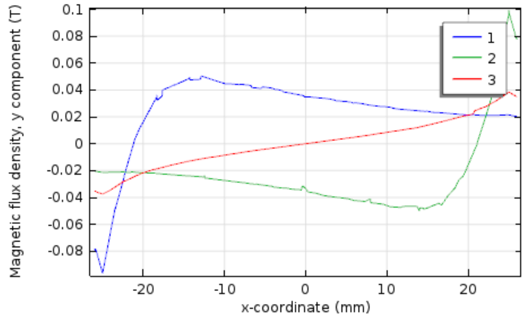
2 Numerical simulation

The problem solution is carried out in COMSOL Multiphysics. COMSOL is an interactive environment for modeling and simulating of the scientific and engineering problems [7-9]. As a result of the numerical simulation the character of magnetic field distribution over the current flowing through the pack of plates in the diagonal direction is obtained. In this case the magnetic circuit is absent.

The blue arrows in Figure 1a show the magnetic flux density and the red lines represent the character of current flowing. Figure 1b shows the graphs of the magnetic flux density distribution over the width of the pack of 50 plates. The total current I_{tot} is equal to 2500 A. It defines as $I_{tot} = N \cdot I$, where N is the number of layers in the pack, I is the current flowing through one layer. Therefore, the generated in this case magnetic field will cause the significant distortion of the main motor's magnetic flux.



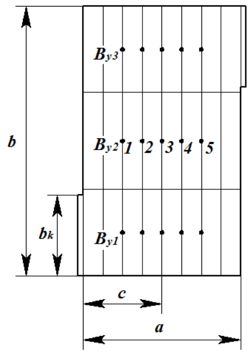
a)



b)

Fig. 1. The character of magnetic field distribution: a - the pack of plates; b - the graphs of the flux density over the width: 1, 2 - at the ends of the pack; 3 - in the center of the pack.

The torque motor parametric model is built in T-flex CAD system. Figure 2a shows the tape winding fragment with the areas, where the flux density is defined. This is allowed to simulate the relative movement of the motor's magnetic system and the tape winding.



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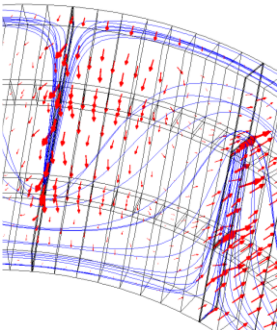

b)

Fig. 2. The tape winding fragment: a - the subdomains of the tape winding pack; b - the character of the resulting magnetic flux density distribution at the position 1.

During the numerical simulation the flux density is determined in the positions indicated in Figure 2a by three variants:

I variant - Current flows through the tape winding. The magnetic circuit is absent.

II variant - Current flows through the tape winding. The motor's rotor is made of ferromagnetic material, without permanent magnets.

III variant - Current flows through the tape winding. The rotor is represented by neodymium magnets and ferromagnetic poles.

If the current through the tape winding is absent, the motor's magnetic field will have the uniform magnetic field with the flux density about 0.4 T. If the current flows through the tape winding (variant III), the main magnetic flux will deform. Figure 2b shows the character of the resulting magnetic flux density distribution at the position 1.

The obtained results allow to define the flux density distribution in the air gap. These data are available at the different pole positions. In this case, the five positions are selected.

3 Results and Discussion

Based on (3), results of numerical simulation and the previously obtained values of double integral for all selected subdomains of the tape winding pack the developed motor's torques over the five selected rotor positions are calculated. The results are shown in Figure 3 by the dependences for two values of the total current, flowing through the tape.

The curves 1 and 3 represent the dependences without the effect of control current, flowing through the tape winding. The curves 2 and 4 take into account the effect of that current.

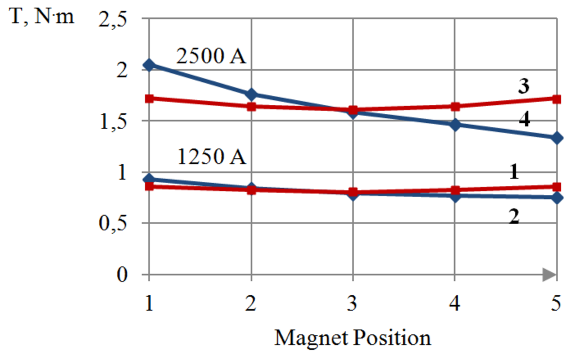

Fig. 3. The motor's torque over the angular movement.

4 Conclusion

From the graphs in Figure 6 it follows that taking into account the effect of the control current the dependence of the developed torque over the permanent magnet position is deformed. In particular, there is the rotation of the dependence relatively to it center. The reversal current cause the rotation in the other direction.

At the total current of the tape winding 2500 A the deformation reaches (25-30) %; at 1250 A – 12 %. In some technical devices, such parameters are permitted. If it is necessary the dependence can be corrected for example by the additional side cuts inside the tape winding plate [6].

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