

Research Article

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Model of the multipolar engine with decreased cogging torque by asymmetrical distribution of the magnets

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Abstract: This paper presents the results of field calculations of cogging torque for a 12-pole torque motor with an 18-slot stator. A constant angular velocity magnet and the same size gap between $n-1$ magnets were assumed. In these conditions, the effect of change of the n -th gap between magnets on the cogging torque was tested. Due to considerable length of the machine the calculations were performed using a 2D model. The n -th gap for which the cogging torque assumed the lowest value was evaluated. The cogging torque of the machine with symmetrical magnetic circuit (the same size of gap between magnets) was compared to the one of the asymmetrical machine. With proper choice of asymmetry, the cogging torque for the machine decreased by four times.

Keywords: permanent magnets, cogging torque, multipolar machines, torque machines

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1 Introduction

Torque motors are designed to operate as static machines and at low speeds [1, 2]. They are characterized by high nominal torques, characterised by large dimensions and precise workmanship. Since they operate in positioning systems, without transmission gear, there is no mechanical backlash. A shortcoming of these motors is a considerable cogging torque [6] associated with a large number of permanent magnets located on the rotor [3, 4]. Our paper deals with minimization of the cogging torque. The impact of asymmetry in magnet distribution on the cogging

torque for a 12-pole torque motor whose stator has 18 slots is analyzed.

2 Methods of minimizing of a cogging torque

The methods to minimize the cogging torque that are most frequently used can be counted as:

- The use of magnetic wedges,
- The application of the pitch of the stator cribs,
- The application of the pitch of the permanent magnet rotor,
- The application of staves in stator teeth,
- The asymmetry of staggered magnets on the periphery of the rotor.

One of the most popular is to use a pitch of the stator crib or the pitch of the permanent magnets [11]. Almost complete elimination of the cogging torque is possible when employing a continuous pitch of stator crevices as well as the continuous bevel of the magnets. The realization of the continuous bevel considerably complicates the manufacturing process. The cost of production is greatly increased by the cumbersome shape of the magnets and difficulties with the technology of magnetizing. Therefore, while this method is used for individual solutions it is not suitable for mass production.

Another method of limiting the cogging torque is to create cutouts on the surface of the stator teeth. The aim of those extra cuts is to imitate the openings of creches. The width of the cuts is identical to the actual width of the stator crevice and the distribution is symmetrical. Thanks to this method there is a significant limitation of the maximum value of the cogging torque. In order to be effective, this technique needs to consider the number of cutouts in the stator teeth to the number of cogging moments that occur during the rotor rotation by the crest level. Additionally, it should be noted that the amplitude of the funda-

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mental harmonic is greater than the amplitude of the remaining harmonics.

3 Evaluation of the cogging torque

3.1 Symmetrical distribution of the magnets

In Figures 1 and 2 the magnetic circuit and the density plot of the flux density are shown, respectively.

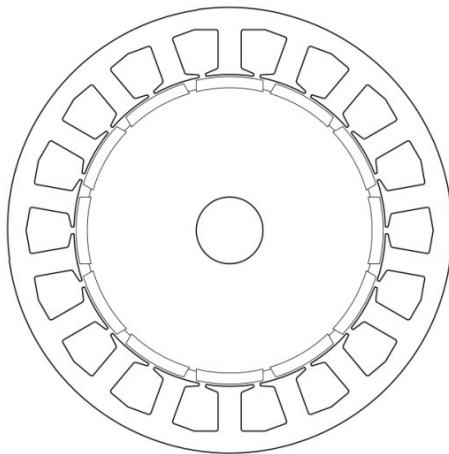


Figure 1: Magnetic circuit with symmetrical distribution of magnets

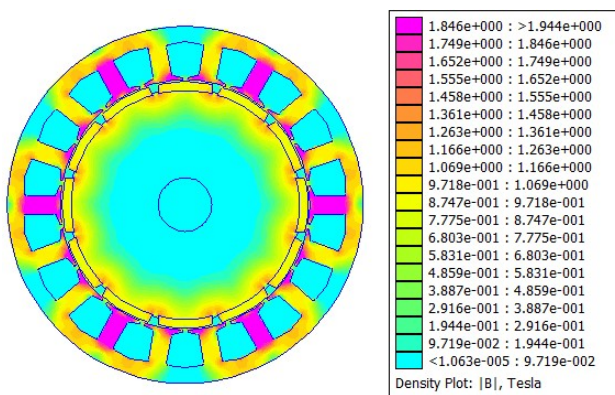


Figure 2: Flux density plot for the motor with symmetrical distribution of magnets

The asymmetry of the distribution of magnets on the rotor is applied here as the method to minimise the cogging torque. Initially, a constant angular velocity of the magnet and the same size gap between twelve magnets (Figure 1) were assumed. Then, maintaining the dimensions of the magnets, the size of one gap was changed while the

other gaps remained equal. Under these conditions, the influence of the width of the single gap between magnets on the cogging torque was tested. Due to the considerable length of the machine in relation to the diameter calculations were performed using a 2D model [7]. The simulation model was developed, and field calculations were carried out in the FEMM 4.2 [8]. For the adopted magnetic circuit, the size of one gap was changed every 0.1° . The width of gap for which the cogging torque takes the minimum value was determined.

3.2 Asymmetrical distribution of magnets

The modified magnetic circuit and the flux density plot are shown in figures 3 and 4, respectively.

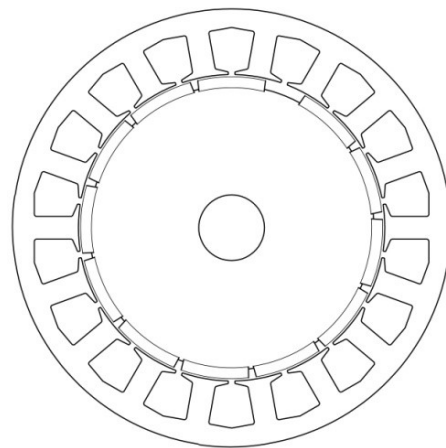


Figure 3: Magnetic circuit with asymmetrical distribution of magnets

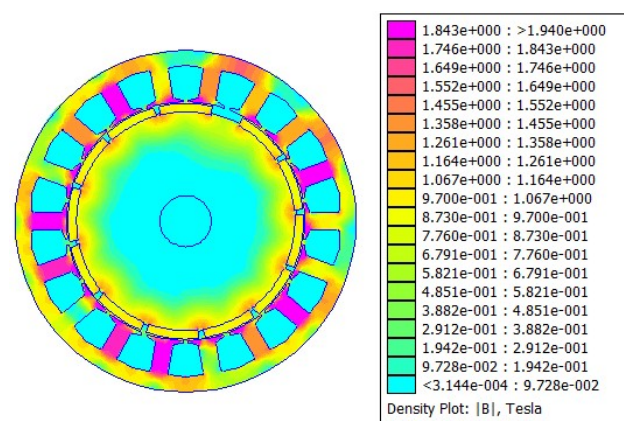


Figure 4: Flux density plot for the motor with asymmetrical distribution of magnets

4 Distribution of the magnetic induction in the gap

For the calculation of magnetic induction in the gap, the FEMM 4.2 [9, 10] finite element method (FEM) program was used. This takes into account the saturation of the respective elements of the magnetic circuit, the characteristics of magnetization of the ferromagnetic elements and the complex shapes of the circuit.

The distribution of the magnetic induction in the air gap for the symmetrical distribution of the magnets is repetitive in full rotation of the rotor.

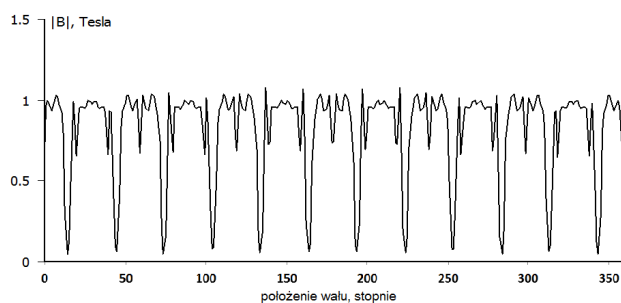


Figure 5: Distribution of induction in the gap at the symmetrical distribution of the magnets

Figure 5 shows the distribution of induction in the gap in the case of symmetrical distribution of magnets on the rotor. Fixed magnets have been distributed on the rotor at intervals of 30° .

For the asymmetrical distribution of magnets, there is a difference in the distribution of magnetic induction in the gap. The indentation chart in the slot has a significantly smaller amplitude in the full rotation of the motor. The distance between N-1 magnets was reduced by 2.5° , which increased the distance between the two magnets. The decay of the induction in the gap shows a significant decrease in the induction, and its rapid increase at the large gap between the magnets.

Figure 6 presents the magnetic induction in the air gap with respect to the shaft position.

For the calculation and determination of the smallest cogging torque, the method of minimizing the optimization of the engagement torque has been utilized, by applying the asymmetry of the permanent magnets to the rotor of the torque motor. The smallest cogging moment was determined by an empirical method. By changing the spacing of the magnets at 0.5° , the distance between the two magnets is increased. However, the distance between

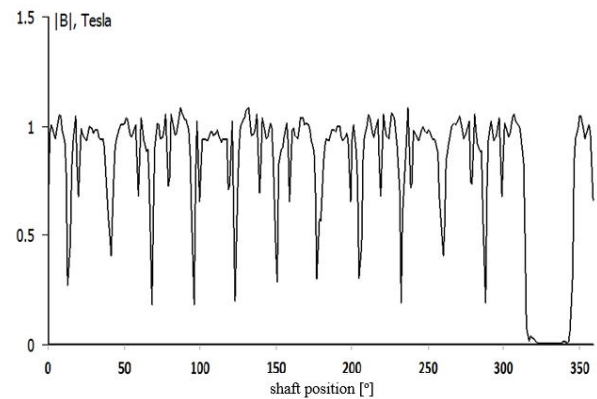


Figure 6: Distribution of induction in a gap with asymmetrical distribution of magnets

the N-1 magnets remained the same. A summary of the results is shown on Figure 7.

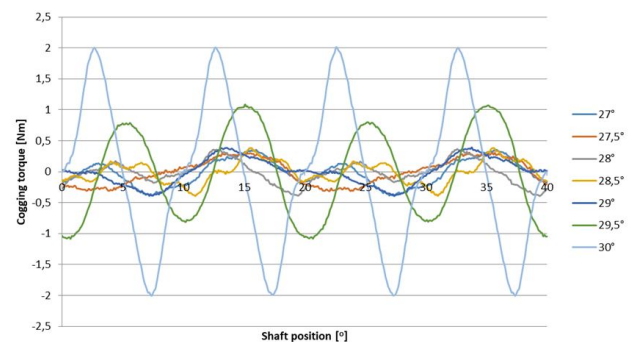


Figure 7: Diagram of change of the cogging torque when changing the magnitude of the magnets by 0.5°

As it is presented in the attached chart, the maximum value of the cogging torque with the correct selection of the magnets is decreased in value four times. When the spacing between two magnets is too great, the value of the cogging torque increases.

5 Results

Figure 8 shows that the value of the cogging torque depends strongly on small asymmetries in the distribution of magnets.

The cogging torque minimized by this method is four times smaller than the one observed for conditions of symmetry. The nominal torque of the machine is practically unchanged. With an asymmetric magnetic circuit, the rotor should be balanced despite the low speed of the motor.

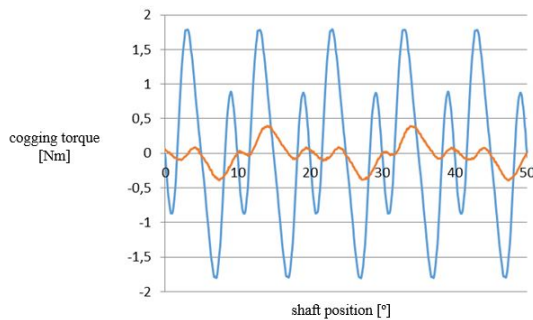


Figure 8: Cogging torque for symmetrical and asymmetrical magnetic circuit of the motor. Blue line – symmetrical, orange line – asymmetrical

The mesh elements impact on the accuracy of cogging torque determined by FEMM 4.2, and the value of the angle of rotation for subsequent calculations, and the highest number of grid points should be placed in the air gap. Too few grid elements and a large jump resulted in significant inaccuracies and shifts in results. The accuracy of calculations and the significance of the aforementioned conditions can be seen by comparing the values of Figures 7 and 8. These values, however, slightly differ from each other.

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