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doi:10.15199/48.2015.01.47

The shape of surface in rotors pole as a forming element of torque and braking torque in hybrid step motor with permanent magnets

Streszczenie. *Artykuł stanowi analizę przydatności formowania gęstości strumienia w hybrydowych silnikach krokowych z magnesami stałymi. W obliczeniach zastosowano Metodę Elementów Skończonych. Wszystkich symulacji do wyliczenia gęstości strumienia, siły, momentów dokonano w środowisku ANSYS. W poprzednich publikacjach autora przedstawiono zastosowania zmian gęstości strumienia do polepszania właściwości silników z magnesami stałymi. Symulacje pokazują różnice w pracy silnika przy zastosowaniu metody zagęszczania strumienia. Może to być przydatne do poprawiania właściwości silników konstruowanych w oparciu o magnesy stałe.* (***Kształt powierzchni nabiegunników wirnika jako element formujący moment obrotowy oraz zaczepowy moment hamujący w hybrydowym silniku krokowym z magnesami stałymi.***)

Abstract. *In the paper the results of analysis concerning magnetic circuits with modelling flux density in hybrid step motor with permanent magnets has been presented. In the research FEM Method has been applied. All simulations for computing flux density, forces, and torques have been performed by the program Ansys. Application of this method in hybrid step PM Motors has been presented in previous publications. The simulations have shown differences in the work of the electrical motor with a density system. It can be used as the way to increase desired parameters of the drives.*

Słowa kluczowe: magnes stały, silnik, strumień magnetyczny
Keywords: permanent magnet, motor, magnetic flux

Introduction

Calculations using the method of Maxwell tensor force allow rapid evaluation of new engine design. Computing power permits to increase the precision and speed of calculations. This makes it easy to create numerous simulations preserving time and money needed to produce new constructions. The method is particularly useful for designing new kinds of electomagnetic structures, including electrical motors. Indirectly, this method can be used for noise reduction [6] or optimization of magnetic circuits [5]. It is important to assume very big difference between the magnetic permeability (minimum ratio 1/1000) in those two analyzed materials (air and iron). In the calculations the normal component of flux vectors is placed in the air gap, and a big difference of magnetic permeability between the air and electromagnetic steel was assumed. The presence of the air gap in the analyzed region meets these conditions. Author is trying to construct the permanent magnets motor which in a natural way is able to take advantage of cogging torque. It can be used to break without using electricity. Permanent magnet generates constant flux. It is possible increasing the forces and torques by increasing flux density. The only way to increase the flux density has been shown in Fig. 1. According to the formula [1] reducing cross-section of magnetic circuit results in the flux density increase.

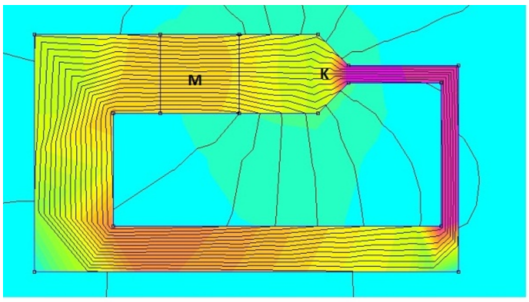

Fig.1 Principle of operation of magnetic concentrators.

The concept of concentrator has been presented in Fig 1. Permanent magnet M is placed in a magnetic circuit. Increase in the flux density passing through the concentrator can be observed.

$$B = \frac{\varphi}{s} \tag{1}$$

Previous publications [5, 6] discussed the influence of a magnetic concentrator on the cogging torque and the braking force of the rotor.

Assumptions of the project

The main aim of the author is to further increase the forces and torques in the motor. In the design described in this article the definition of induction is described by formula (1). If the surface of the pole decreases, as in Fig. 2, the flux flows through the reduced surface through the teeth of the pole piece. The permanent magnet flux will be concentrated.

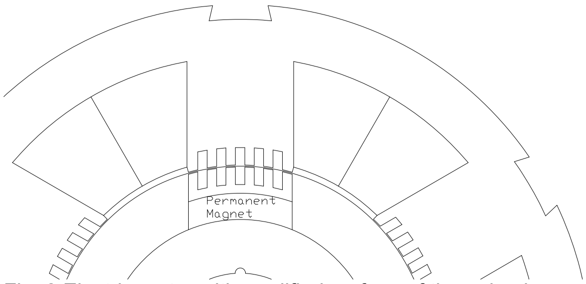

Fig. 2 Electric motor with modified surface of the pole piece.

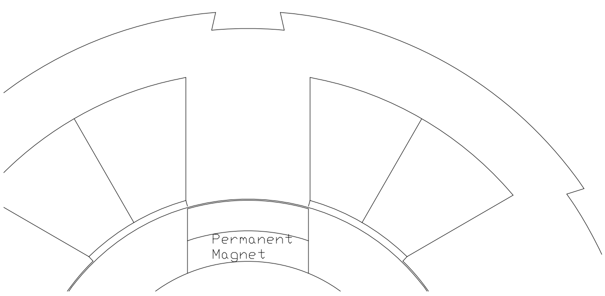

Fig. 3 Electric motor with smooth surface pole piece.

With the increased concentration of flux, the increase of the local forces and torques in the engine can be expected. In order to compare the impact of model with teeth on the surface of the pole piece, the simulation of work of engine with a smooth surface of the pole pieces has been performed. Such a model is shown in Fig. 3.

Computing methodology

All simulations have been performed with the program Ansys useing the Maxwell Stress Tensors (MST) methodology [3]. Zero boundary conditions have been assigned around the machine. The area around the motor has been divided into 300.000 triangle elements. The elements have different dimensions, depending on the importance of the considered area. The sensitive space around the air gap, sharp shapes around the poles, was analyzed with finer mesh. The software can recognize moving and non-moving elements. The motor has been divided on the stator with six winding poles as a nonmoving part of the motor, and the rotor with four poles magnetized by permanent magnet elements as moving elements. The shape of air gap between the stator and the rotor is very important. The rotor axis is placed perpendicularly to the surface of Fig.1. Computing force has been calculated from:

(2) $$F = \int_C \left[\frac{1}{\mu_0} B(B.n) - \frac{1}{2\mu_0} B^2.n \right] dC$$

and torque:

(3) $$T = r * F$$

where: B- momentary value of induction in the air gap B [T], n- unit vector, perpendicular to the surface of rotor. μ_0- magnetic permeability of vacuum $\mu_0 = 4\pi \cdot 10^7$ [H/m]

Value of torque is calculated from the formula (3) taking the radius of rotor as r [m]. It is important to assume a very big difference between magnetic permeability (minimum 1/1000) in those two analyzed spaces (air and iron). In the calculations the normal component of flux vectors in the air gap, and a big difference of magnetic permeability between the air and electromagnetic steel was taken. The presence of the air gap in the analyzed region fulfills these conditions.

Computational result

All simulations for computing flux density, forces, and torques have been performed by the Ansys program. As expected, the dependence of the torque from the angle of rotation of the rotor is significantly different in both cases. It is shown in Figure 4 and 5.

The graph in Fig. 4 refers to the motor with serrated rotor poles. It can be seen how the shape of the pole piece affects on the torque. On the axis T, time 0.1 s corresponds to rotation of the rotor pole by one tooth. It should be noted that the amplitude of the oscillating torque changes the size +/- 7.1 Nm and is only a cogging torque without using energy.

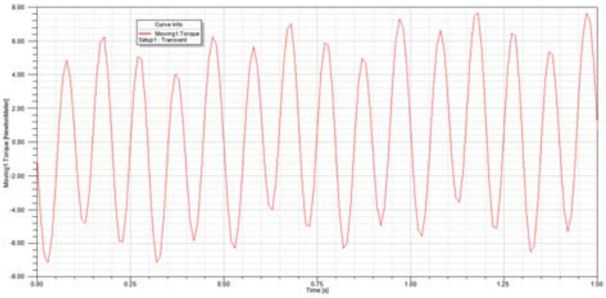

Fig. 4 Engine torque with a serrated surface of the rotor pole.

This suggests the possibility of using this construction as the breaking torque motor. In case of exceeding the maximum torque the motor does not rotate to the next pole piece (in the article it is 60 degrees). It is trying to stop on the next tooth of pole piece. This phenomenon allows the use of this type of engine as a braking system. The occurrence of the active load torque of the drive system requires the use of an emergency braking system without the use of electric energy. The PM motor with a serrated rotor can be used as a braking system for the active torque.

The second simulation has been performed for a pole pieces with the smooth surface. The shape of the cogging torque is shown in Fig. 5.

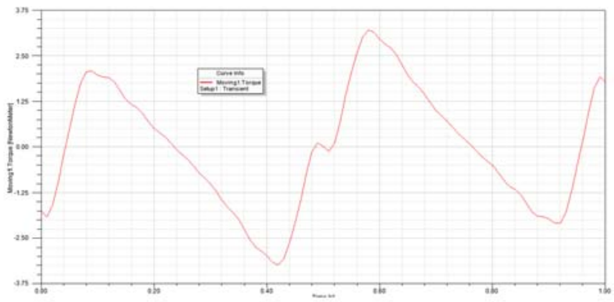

Fig. 5 Cogging torque for a motor with a smooth surface of the rotor pole piece.

There are clear differences between the moment generated by the toothed rotor and a rotor with full pole pieces. The design with full pole pieces has a much smaller cogging torque. Low density of energy field in the second case reduces the size of the cogging torque. The maximum amplitude of the cogging torque is + \ - 3.25 Nm. The low cogging torque arises from the principle shown in the Fig. 1. The principle illustrated in Fig. 1 gives positive results in the construction of engines.

Conclusions

Increasing the density of the energy in the motor air gap gives positive results. This design allows increasing the cogging torque. The specific shape of the air gap caused the energy concentration in that design. The teeth on the surface of the pole pieces made it possible to change the size of the air gap. The size of the air gap was increased in the area between the teeth and was reduced in the teeth. Changing the size of the gap, forces the concentration of flux on the stators and rotors teeth. All this made it possible to double the cogging torque. Breaking with over twice the torque is a highly desired result. It should be noted that this is achieved without the use of energy.

Comparing the results in Table 1, the positive effects of changes in the surface of the pole pieces can be noticed.

Table 1. Comparison of the simulations results

Cogging Torque	Amplitude
Flat surface [Nm]	+/-3,25
Teeth surface [Nm]	+/-6,1
Difference [Nm]	2,85

Increasing the flux density in the teeth of the motor may increase eddy current losses in this space. This is due to saturation of the magnetic circuits in that area. However, it is important to notice the location of these areas. They are located in the area of maximum rotation speed. This is an area currently most intensively cooled. In addition, the saturation volume of the region is small. Losses, which are not big, will be analyzed in the future.

In summary,

- The use of the teeth on the surface of the pole pieces gives positive results using the engine as a braking system with the cogging torque.

- Using the cogging torque for braking saves electricity,

-Breaking with the cogging torque does not cause losses. They can be used wherever breaking time (blocking movement) is extended.

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