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The use of shaping face of pole in rotor as a component of molding cogging torque in Permanent Magnet motor in self-breaking systems

Streszczenie. *Artykuł stanowi analizę przydatności formowania gęstości strumienia w silnikach z magnesami stałymi. Ograniczona gęstość strumienia generowana przez magnesy stałe nie zawsze pozwala na osiągnięcie celów. Zagęszczenie strumienia tak jak przedstawiono to w poprzednich pracach autorów pozwala na intensyfikację zadań stawianych dla maszyn, w konstrukcji których użyto magnesów stałych. W poprzednich pracach autorzy przedstawili układ z koncentratorem magnetycznym. Pozwalało to dopasować kąt opasania nabiegunnika do gabarytu magnesu stałego. Dalszego zagęszczenia strumienia można dokonać poprzez zmniejszenie pola przekroju obwodu magnetycznego. W artykule przedstawiono propozycję takiego rozwiązania, oraz dokonano symulacji i analizy problemu przy pomocy metody elementów skończonych, z użyciem programu Ansys.* ***Formowanie gęstości strumienia w silnikach z magnesami stałymi***.

Abstract. *In the paper the results of analysis concerning magnetic circuits with shaping flux density in motor with permanent magnets have been presented. In the research FEM Method has been applied. All simulations used to compute flux density, forces, and torques have been performed in the program Ansys. The application of this method in self-loocking PM Motors was discussed in authors' previous publications. The simulations showed differences in work of machines with density system. It can be used as the way to increase the desired drives parameters values.*

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

Introduction

Active torque appears everywhere where external forces working on a drive are observed. They can be a gravity field, or wind, flowing water and so on. External devices cooperating with a drive must sometimes be stopped. Self-loocking electrical motor can be used as a natural way to do it. In [1] authors proposed a solution to do that using the permanent magnets. This electromagnetic construction has large cogging torque. All forces increase by directing the flux and concentrating it on the air gap between stators and rotors pole piece [2]. All forces can be switched by specific control [3]. Using the same tool as a brake or as an engine causes problems. Permanent magnet has constant flux. It is possible to increase it by the concentrator. The principle of increasing density of the flux using concentrator is shown in fig 1.

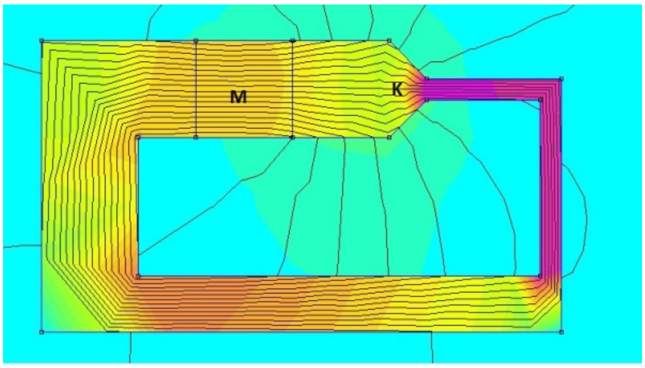

Fig.1. Flux condensation by surface reduction.

Increasing the intensity of inhibiting was achieved by flux condensation obtained by reducing the surface of the pole piece. According to the Authors there is also a different way to increase flux density. It can be obtained by the air gap enlargement.

Directing the flux through the teeth of the rotor and stator pole piece will further increase the flux density in the air gap. This solution is shown in fig 2. Variation of wrapping angle is one way to increase the flux density. The other one is to increase flux density by air gap modification.

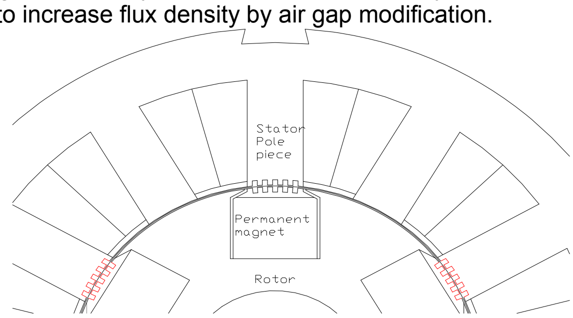

Fig.2. Flux condensation by surface reduction.

The shape of trapeze is the first step of condensation, teeth are the second. In the present paper the analysis of increasing of the flux density by the modification of the pole piece surface has been performed. The increase of the flux denstity by the trapeze shaped concentrator was discussed in [1, 2]. The concentration of flux energy should result in enlargement of the forces and torques occurring in the device.

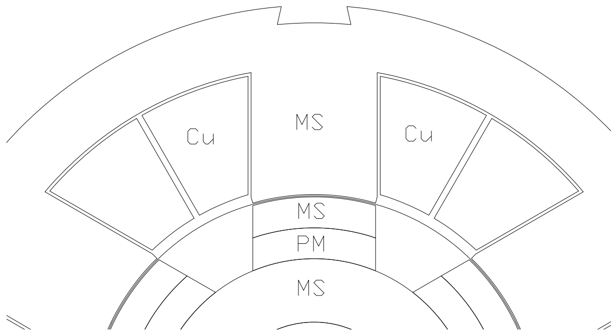

Fig.3. Electromechanical transducer with the smooth pole piece.

Asumptions for the project

It was the intention of the authors to compare two electromechanical transducers: one with the smooth pole piece and the second with concentrator function using air gap modification.Cross section of the first is shown in fig.3, while this of the second in fig 4.

Symbols on the pictures are as follows: MS - electromagnetic steel, PM-permanent magnet, Cu-Cooper. The simulation was carried out taking into consideration all of the conditions specified earlier, assuming the cross-sections presented in fig. 3 and 4 respectively. For the construction of magnetic circuits electromagnetic steel were used. Rotor pole pieces additionally contained permanent magnets.

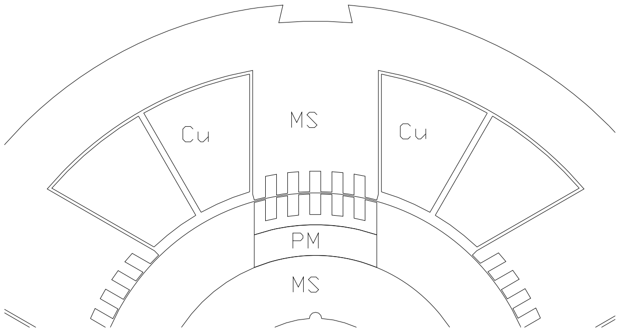

Fig.4. Flux condensation by air gap modification .

Computing methodology

All simulations have been performed with the Ansys program. This piece of software uses the Maxwell Stress Tensors (MST) methodology [4]. 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. Software used in simulation makes it possible to model both: moving and non-moving elements. The motor has been divided onto the stator with six winding poles as a non-moving part of the motor, and the rotor with six poles magnetized by permanent magnet elements as a moving element. The shape of the air gap between the stator and the rotor is very important. The rotor axis is placed perpendicularly to the surface showed in Fig. 3, 4. Considering the formulas for computing force:

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

and torque

(2) $$T = r \cdot F$$

Values in formulas (1) and (2) are as follows: 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 part of flux vectors in the air gap, and big difference of magnetic permeability between the air and electromagnetic steel were assumed. The presence of the air gap in the analyzed region fulfills these conditions.

Computational results

The results of cogging torque simulation have been presented in fig. 5. The time scale of rotation (simulation of 1 sec.) was shown as the rotor rotation with speed of 60°/sec.

In the graph the changes in the torque value are caused by shaping surface of the pole piece. The change amplitude reaches value of 16 Nm (pp). The value of 16 Nm braking torque without electricity is a significant feature, taking into account that the transducer would work as a self-locking system.

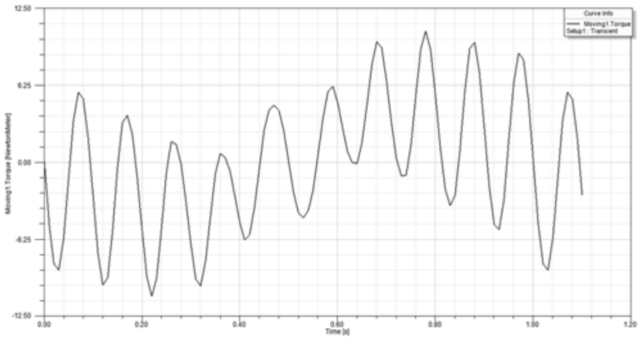

Fig.5. Cogging torque of transducer with air gap modification.

In one moment self-locking system should stop working because we do not want it to brake. It is possible to do it by using specific control. In the fig 6 the result of simulation with current of winding on the level of 10A was shown. Amplitude of braking torque values changed to the level of 7 Nm. It means that it is possible to select current which generate torque on the level of 0 Nm, without any braking.

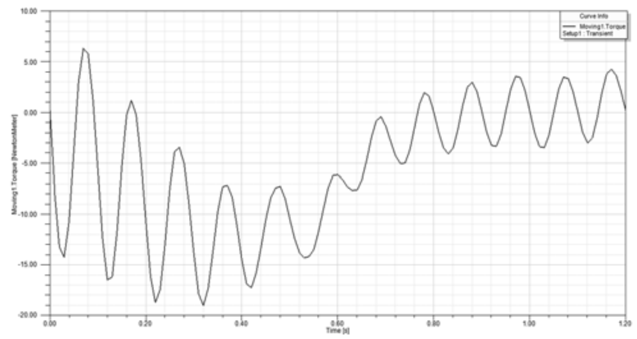

Fig.6. Cogging torque of transducer with air gap modification, Current I=10A.

In order to compare transducers the simulation of the second transducer with smooth surface of pole piece was performed. Results are shown in fig 7. The shape of cogging torque graph shows no vibrations. Value of cogging torque is significantly smaller then in previous transducer +/- 6,3 Nm (pp) only. In order to use that machine as self locking system it is recommended to use the construction with teeth on the surface of pole piece.

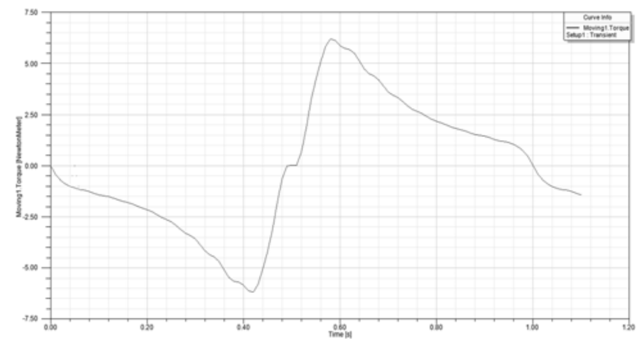

Fig.7. Cogging torque of transducer with air gap modification, Current I=10A.

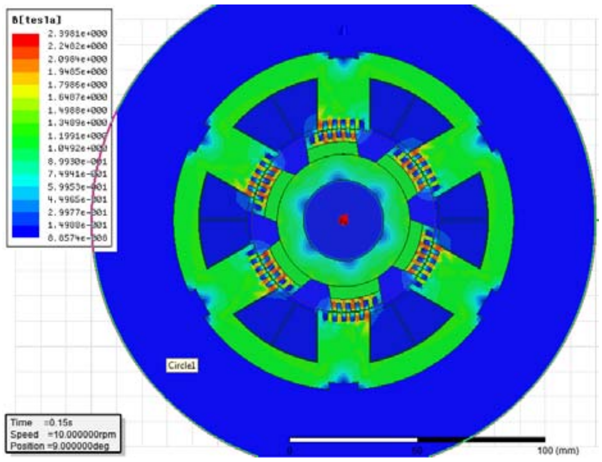

Fig.8. Distribution of flux in the transducer in the absence of control

In fig.8 we can see red parts in the picture. They are parts where density of flux is too high. In these parts there could be too much losses. Problem would be analysed by authors in the future.

Conclusion

Comparing a work of two transducers described in introduction it is possible to draw the following conclusions:

1. Increasing density of flux enables torque and forces in transducer to increase.
2. Concentration of flux can be done by shaping surface of pole piece.
3. Transducer with shaped surface of pole piece has bigger cogging torque.
4. This is valuable feature to use this machine as a self locking system.
5. Changes of cogging torque amplitude causes multiple braking.

All conclusions show great importance when we would use that transducer as a braking system. It is small problem with condensation of flux.

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