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The influence of an air gap around the permanent magnets with the flux concentrator in Permanent Magnet Synchronous Motor with Internal Magnetic Circuits

Streszczenie. *W artykule przedstawiono zalety szczeliny powietrznej wokół magnesu stałego umieszczonego wewnątrz wirnika. Postępowanie takie pozwala na użycie większych magnesów oraz koncentratora. Większe magnesy pozwalają na użycie większych energii umieszczonej w wirniku, koncentrator pozwala na skupienie pola na mniejszej powierzchni co z kolei umożliwia na zwiększenie ilości nabiegunników stojana.(przygotowanie artykułu dla Przeglądu Elektrotechnicznego. (**Wpływ szczeliny powietrznej wokół magnesu stałego na pracę koncentratora strumienia nabiegunnika w wirniku silnika synchronicznego z magnesami stałymi z wewnętrznym obwodem magnetycznym**)*

Abstract. *In the paper the results of analysis concerning magnetic circuits with the air gap around the 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 FLUX 2D v 10.1. The simulations have shown a significant influence of the air gap on the flux concentration and torque in this kind of motors*

Słowa kluczowe: magnes stały, silnik, koncentrator
Keywords: permanent magnet, motor, concentrator

Introduction

Location of constant magnets inside of rotor is very comfortable. Centrifugal forces have strong influence on magnets during rotation. Inside the iron of rotor, magnets are safely placed and they cannot move in any direction.

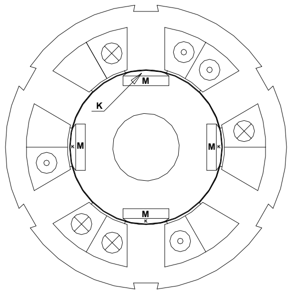

Fig.1. An example of the PM IC SM

The shapes of constant magnets are very specific and they are positioned in many different places [1]. They are very wide and because of it the flux concentration is not so high. Therefore in this kind of motor the value of the cogging torque is not so high but the reluctance torque is also limited. Additionally it can give more noise during rotation [2].

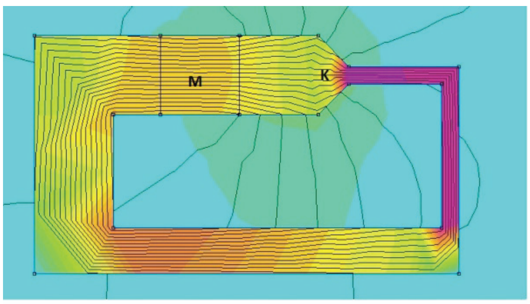

Fig.2. Principle of magnetic concentrators operation.

In the paper an exemplary construction of a rotor described In the construction as on fig.1 the K-letter denotes the place with concentrator. The role of this element is to concentrate the flux. The permanent magnets has constant flux density. Using the concentrator it is possible to increase flux density. On the Fig.2 the letter M is permanent magnet with constant flux density, K is the concentrator. According to :

$$B = \frac{\Phi}{S} \quad (1)$$

With constant flux validity as a consequence of permanent magnet properties, the value of *B is :*

$$\frac{B_1}{B_2} = \frac{S_2}{S_1} \quad (2)$$

where B_1 induction entering the concentrator and B_2 is induction going out of it. To conclude, in that case it is possible to reach higher forces and rotating and cogging torques. In Ref. [4] the positive influence of the concentrator application was shown.. There is another problem with these magnet locations. The flux has tendency of closing inside the iron of rotor without passing through the air gap in the motor, thus the dissipation flux is bigger. Taking this into account, it must be deducted that the energy of constant field taken from permanent magnet does not go to the motor stator. Thus the forces and torques are reduced. In order to avoid it, one should try to decrease the losses. It is possible to do so by increasing the reluctance in the magnetic circuit, where the flux of losses is present. The solution has shown on the fig. 3.

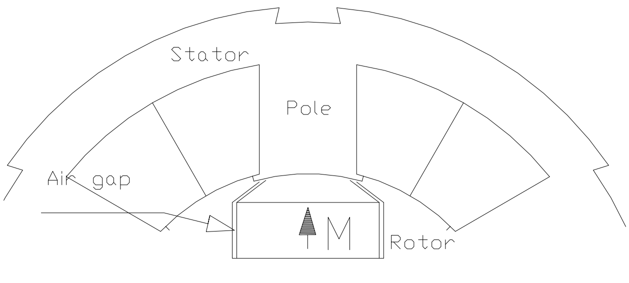

Fig.3. Position of the air gap around permanent magnet in rotor.

The air gap is leaded on both sides of the permanent magnet. This place is chosen on the main path the floating flux of losses. The next place, where the air gap must be leaded, is the space around the concentrator. In this way the main part of flux is going straight to the stators pole.

Computing methodology

All simulations have been performed with the program FLUX 2d V10.1. This piece of software uses 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 200.000 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. Considering the formulas for computing force:

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

and torque

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

Values in formulas (2) and (3) have the meaning 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 μ_0= 4 π . 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 was taken. The presence of the air gap in the analyzed region fulfills this conditions.

Computational result

Taking all of the conditions, specified earlier into account, assuming the cross-section from the fig. 1, the simulation was carried out. The magnetization dependence B=f(H) for the considered materials are in the fig. 4.

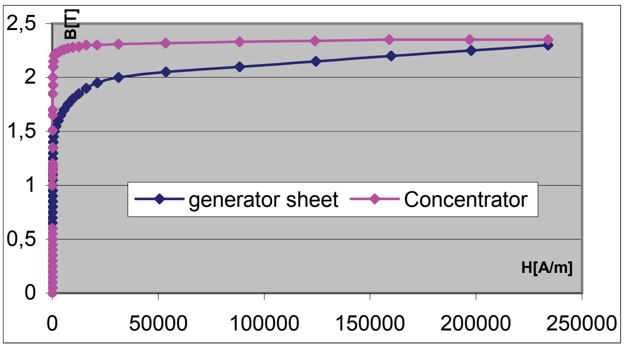

Fig.4. Magnetization charakteristik for the materials of the motor.

The Red B=f(h) dependence is for the material used as concentrator where, B attains B_{max} = 2.35 T.

The simulation has been performed from 0° till 30° rotors turn. The results are shown in the fig. 5 as the dependence of static torque on the angel of rotors rotation.

In the fig. 6 it has shown the principle of it. Looking at the dependence between the static torque and the angle of rotors rotation it is easy to notice the switching control time. On the Fig.5 it is about 13°. In that condition the rotor has a constant positive torque of reluctance. This 2° of rotors rotation movement is the effect of cogging torque influence. Having the static reluctance torque dependence it is easy to predict this displacement. Looking at the Fig. 5 it is reasonable to consider the meaning of application the air gap around permanent magnets in the rotor in this construction. In the Fig. 8 the integral as in formula is shown (5).

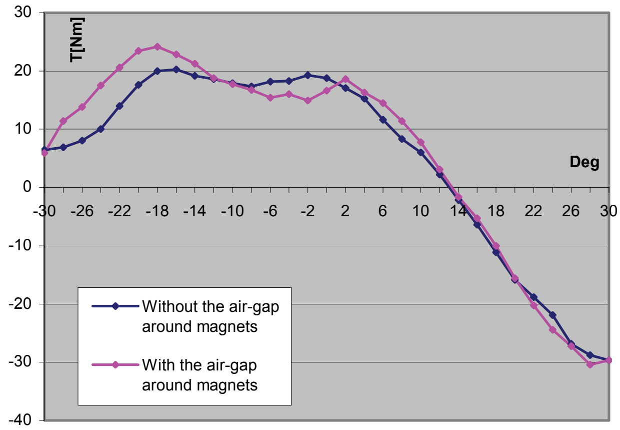

Fig.5. Static torque of reluctance dependence on rotors rotation.

There is possible to notice that static torque is much higher when the air gap is around permanent magnet. Additionally, the concentrator has also the impact on the reluctance torque. In that kind of construction it is possible to use wider permanent magnets as shown on the Fig. 6. It can give more energy in the rotor and the same higher static torque (fig.6) or as it can be seen on Fig.7, less cogging torque. The next advantage of concentrator is to fit the width of permanent magnet to the stators pole.

(5) $$C=\int_{0^\circ}^{13^\circ}Td\deg$$

The diagram shows a significant influence of the air gap leaded as in the Fig.6.

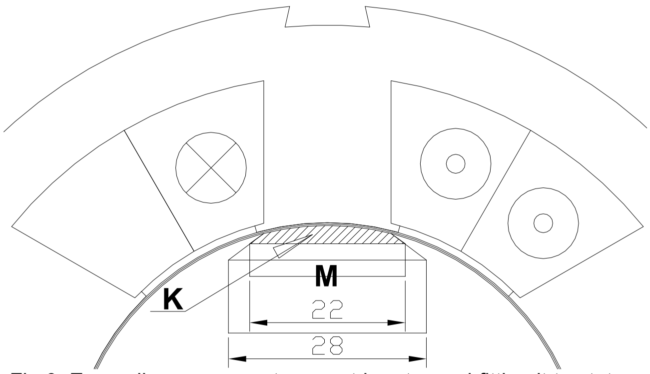

Fig.6. Expanding permanent magnet in rotor and fitting it to stators pole using concentrator.

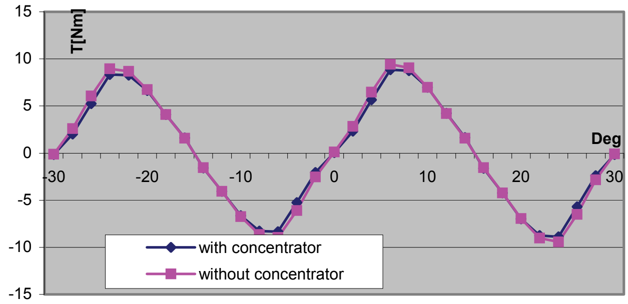

Fig.7. Cogging torque dependence on rotors rotation.

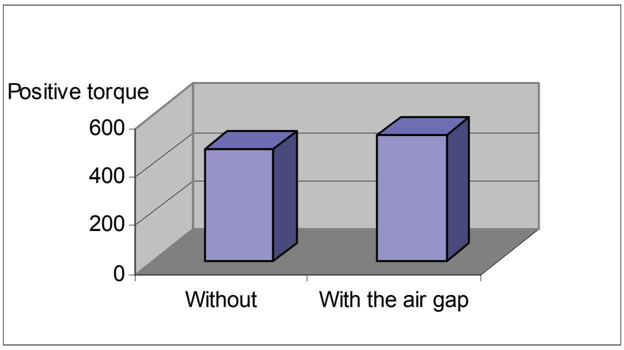

Fig.8. Comparison of the integral for positive torque for construction with and without the air gap around permanent magnets.

Conclusion

The air gap leaded across the flux of loses in the Permanent Magnet Synchronous Motor with Internal Magnet Circuit can give many positive effects. Firstly it reduce the flux looses. Taking this into account, may be deducted that more energy will be processed onto the torque. Secondly the cogging torque is almost the same in both cases. Therefore it can be used as a self-locking motor with almost the same effect while the reluctance torque is much better. Thirdly according to formula (5) the integral "C" for the " air gap " construction is 12% higher. On this basis it may be deducted that the motor will have a higher torque value. All values are shown in the Table 1 below.

Table 1. Comparison of the simulations results

Torque	With air gap	Without air gap
Static [Nm]	(for -18°) 24,17	(for -16°) 20,28
Cogging [Nm]	(for -24°) 8,33	(for -24°) 8,96
Integral C [Nm*deg]	521,02	464,12

To sum up, on the basis of Fig.5 and 8 it may be concluded that the air gap around the permanent magnet in rotor of PMSM IC motor is deeply justified. It can increase the reluctance torque and at the same time efficiency this kind of construction. The main aim of research for authors is a self-locking motor. In that case the cogging torque is the most important. In Fig. 7 it has been shown that the cogging torque in both cases is almost the same. Therefore it may be concluded that the air gap can also be leaded in a self-locking motor. It can be used as a brake in many devices. It is very useful to do something without any energy supply. This kind of brakes do not need any energy during process of braking. It is enough to stop supplying the motor and the cogging torque would start to brake the movement. In the following research, the authors will try to optimize the self-locking motor finding the optimum width for the air gap, the maximum dimension for permanent magnets in rotor and the best proportion and the best material for concentrator. The next problem is the number of poles both for the rotor and the stator. The results shall be published elsewhere.

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