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Analysis of rotor disc thickness in coreless stator axial flux permanent magnet synchronous machine

***Abstract**. This paper presents the analysis of rotor disc thickness in coreless stator axial flux permanent magnet synchronous machine (AFPMSM) with double external rotor and internal stator. An important advantage of these types of machines is that rotors can be implemented by using massive ordinary construction steel. Due to the high possibility of large weight of AFPMSMs there is a tendency to implement as lightweight design as possible. In this work, the influence of rotor disk thickness on AFPMSM characteristics is investigated.*

***Streszczenie.** Artykuł prezentuje analizę grubości dysku wirnikowego w maszynie synchronicznej ze strumieniem osowym i magnesem trwałymz podwójnym zewnętrznym wirnikiem i pojedynczym wewnętrznym stojanem. Ważną korzu=yścią stosowania tego typu maszyn jest to, że wirniki mogą być implementowane za pomocą masywnej stali konstrukcyjnej. Dużej możliwości osiągnięcia dużej wagi w tych maszynach, istnieje tendencja do omplementowania tak lekkich materiałów jak to tylko możliwe. (**Analiza grubości dysku wirnikowego w maszynie synchronicznej ze strumieniem osiowym i magnesem trwałym**).*

Keywords: axial flux, permanent magnet, synchronous machine, rotor thickness.
Słowa kluczowe: strumień osiowy, magnes trwały, maszyna synchroniczna, grupość wirnika.

Introduction

Nowadays, the use of coreless stator axial flux permanent magnet synchronous machines (AFPMSM) is increasing. Due to the relatively large weight of these types of machines there is a tendency towards the implementation of the machines as lightweight as possible. In this work, the influence of rotor disk thickness on double rotor AFPMSM characteristics is investigated. Authors in [1-3] have presented different approaches for the calculation of efficiency or iron losses in other electrical machines types. On the other hand, rotor core lamination of AFPMSM presented in this paper is not required due to negligible losses in rotor iron. Therefore, rotor can be implemented by using massive ordinary construction steel.

For the analysis the existing prototype AFPMSM was chosen. 3D numerical model of AFPMSM was built and magnetic field distribution was calculated by using finite element method (FEM) with Ansys software package. In order to select as thin as possible but still appropriate thickness of rotor disks (d_{Fe}) the AFPMSM back electromotive force (EMF) and magnetic field distributions were calculated. Fig. 1 presents the topology of double sided coreless stator AFPMSM, where: d_s – stator thickness, d_m – thickness of permanent magnets (PMs), d_{ag} – thickness of air-gap, d_{Fe} – thickness of rotor disc, τ_p – pole pitch, τ_m –angle of permanent magnent (PM), τ_t - coil pitch, r_o – outer radius of rotor disc, r_i – inner radius of rotor disc.

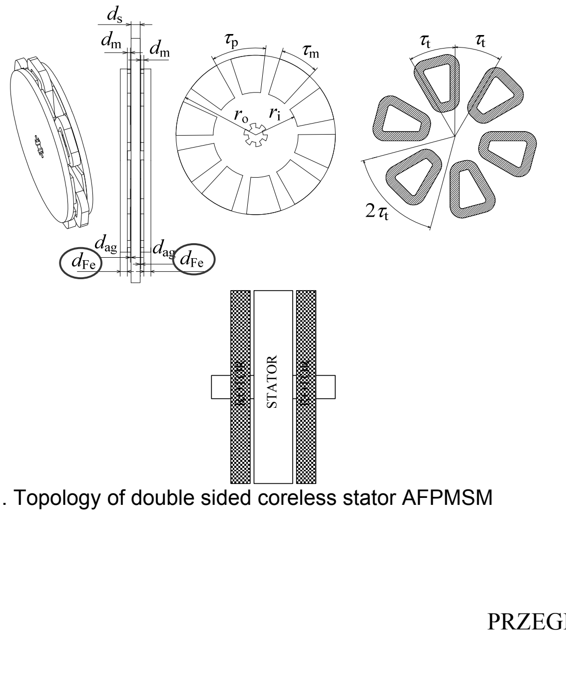

Fig.1. Topology of double sided coreless stator AFPMSM

Motivation for the work presented in this paper is as follows:

- Axial flux permanent magnet synchronous machines can have high power density (less mass and volume per watt).
- Rotor discs present an important share of total machine mass.
- Disc shaped construction gives the possibility to use these machines in the wheels of electric vehicles [4] or outside the wheel.
- European regulations foster the member states to find the solutions about efficient use of energy and materials and CO_2 emissions reduction.
- Electric vehicles seem to be the solution for future transport.

Method of analysis

Magnetic field distribution in AFPMSM was calculated by using FEM within Ansys software package. Due to the symmetry of AFPMSM along axial direction (Fig.1) and long computational time the number of elements was reduced by using this symmetry. Therefore the model of one half of AFPMSM was used for magnetic field calculation.

In order to validate the characteristics obtained by using FEM the analytical method via magnetic vector potential could also be used but it cannot be used for the calculation of magnetic field distribution in the rotor steel disc due to the assumption of infinite permeability of the iron.

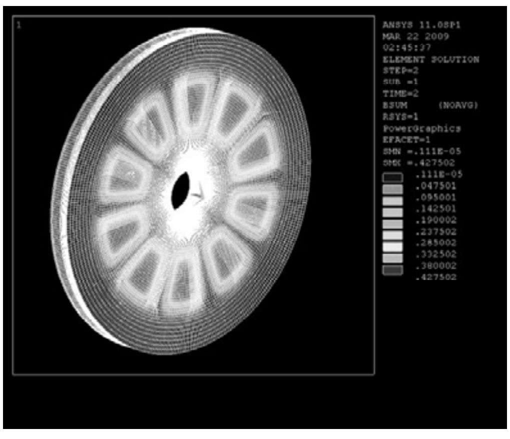

Fig.2. Magnetic field distribution in AFPMSM

Influence of rotor thickness on magnetic field distribution by permanent magnets

Figure 3, 4 and 5 present the instantaneous distribution of normal component of magnetic flux density due to PMs along the half of the length of the circumference which corresponds to the middle radius of PM and to the surface, which is:

- 1 mm shifted from the boundary between the PMs and the rotor disc to the interior of the rotor disc (Fig. 3.);
- the boundary between the PMs and the rotor disc (Fig. 4.);
- for one quarter the stator thickness shifted from the beginning of the stator (boundary with the air-gap) towards the inside of the stator (Fig. 5.).

In each figure (see Fig. 3-5 and 10-12) the rotor disc thicknesses of 3, 5, 7 and 11,6 mm were compared.

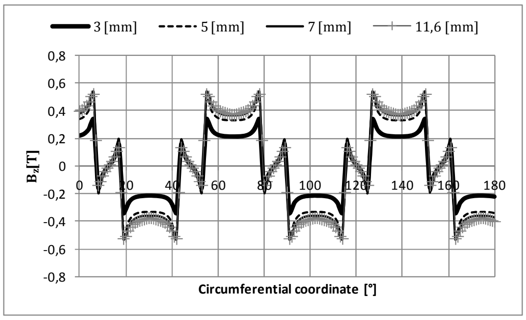

Fig.3. Normal component of magnetic flux density (1 mm shifted from the boundary between PMs and rotor disc to the interior of the rotor disc)

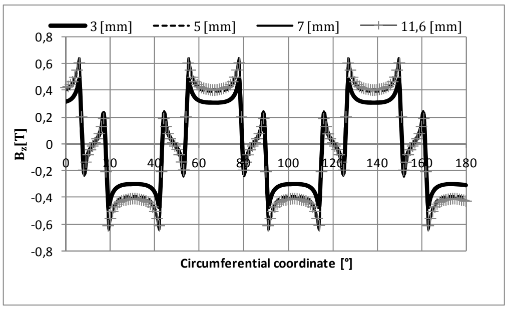

Fig.4. Normal component of magnetic flux density (at the boundary between PMs and rotor disc)

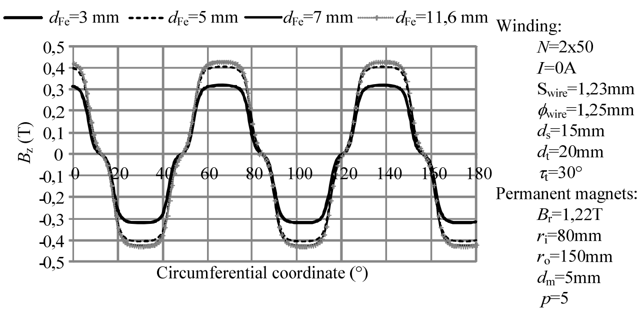

Fig.5. Normal component of magnetic flux density (for one quarter of the stator thickness shifted from the boundary between the stator and air-gap towards the inside of the stator)

Figures 6, 7, 8 and 9 present normal component of magnetic flux density distribution due to PMs at the centre of one of the PMs along the axial direction through the whole machine model at the different rotor disc thicknesses (D):

- 3 mm in Fig. 6;
- 5 mm in Fig. 7;
- 7 mm in Fig. 8;
- 11,6 mm in Fig. 9;

where: A – half of the stator thickness, B – air-gap, C – permanent magnets, D – rotor disc thickness, E – surrounding air, d – dimension of the model and its parts starting from the centre of the stator towards the surrounding air in axial direction, B_z – normal component of magnetic flux density.

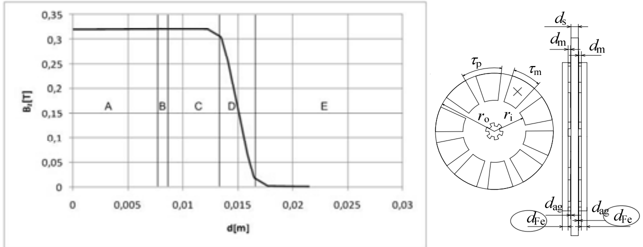

Fig.6. Normal component of magnetic flux density distribution (rotor disc thickness is 3 mm)

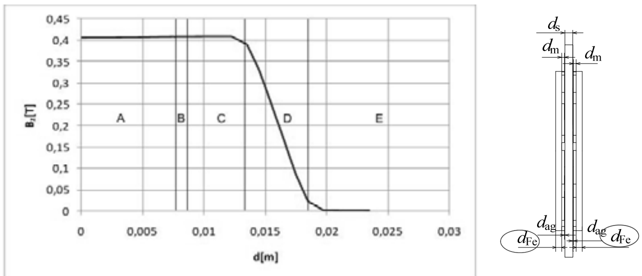

Fig.7. Normal component of magnetic flux density distribution (rotor disc thickness is 5 mm)

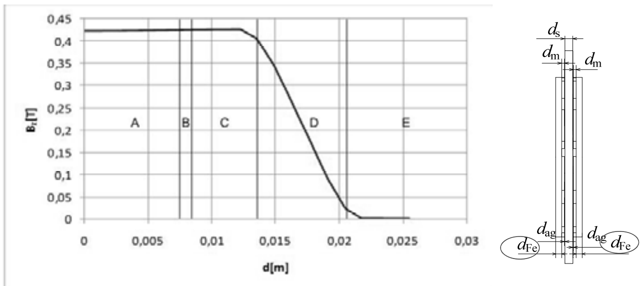

Fig.8. Normal component of magnetic flux density distribution (rotor disc thickness is 7 mm)

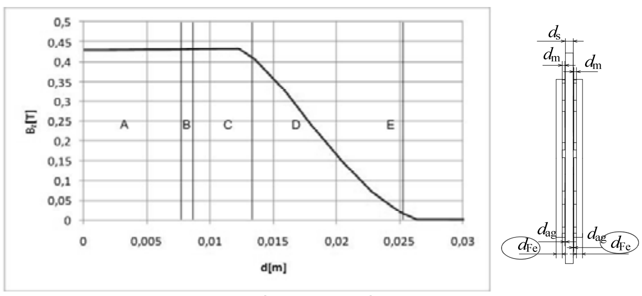

Fig.9. Normal component of magnetic flux density distribution (rotor disc thickness is 11,6 mm)

Figure 10, 11 and 12 present distribution of tangential component of magnetic flux density due to PMs along half of the length of the circumference which corresponds to the middle radius of PM and to the surface, which is:

- 1 mm shifted from the boundary between the PMs and the rotor disc to the interior of the rotor disc (Fig. 10.);
- the boundary between the PMs and the rotor disc (Fig. 11.);

- for one quarter of the thickness of the stator shifted from the beginning of the stator (boundary with the air gap) towards the inside of the stator (Fig. 12.).

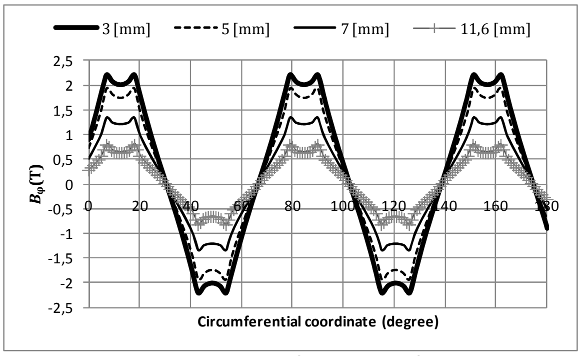

Fig.10. Tangential component of magnetic flux density (1 mm shifted from the boundary between PMs and rotor disc to the interior of the rotor disc)

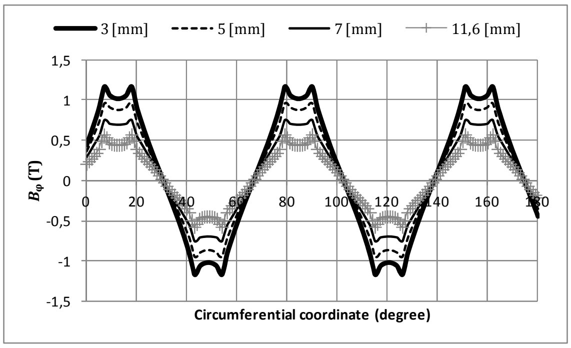

Fig.11. Tangential component of magnetic flux density (at the boundary between PMs and rotor disc)

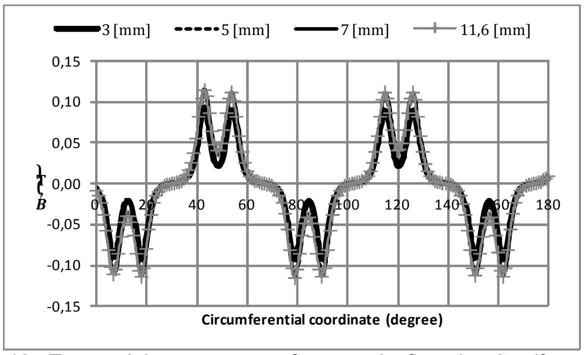

Fig.12. Tangential component of magnetic flux density (for one quarter of the stator thickness shifted from the boundary between the stator and air-gap towards the inside of the stator)

Influence of rotor thickness on electromotive force of AFPMSM

An important advantage of AFPMSM with external rotor topology and surface mounted permanent magnets is that magnetic flux density variation in iron rotor discs can be assumed as negligible and therefore eddy currents and rotor losses can be neglected. For this reason ordinary structural steel formed into disc shape instead of ferrites, metallic powder or laminated steel can be used.

Fig. 13 presents the electromotive force (EMF) according to displacement and rotor thickness. The comparisons between EMF waveforms show the maximum magnitude at rotor disc thickness of 11,6 mm, which is maximum rotor disc thickness in the proposed analysis. Moreover, the minimum thickness of the rotor disc, which is still suitable to avoid the sharp deterioration of AFPMSM characteristics, is determined as well.

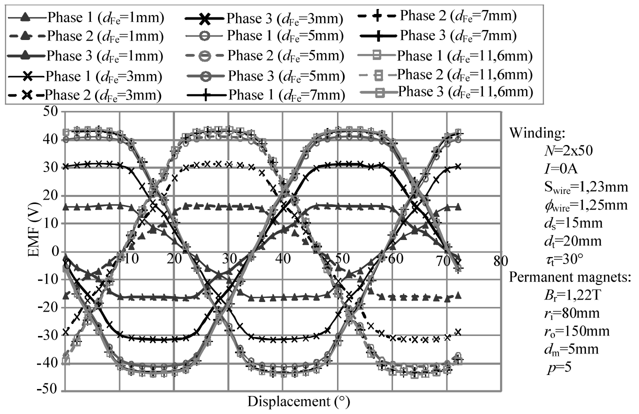

Fig.13. Electromotive force according to displacement and rotor disc thickness

From the results in Fig. 13 it can be seen that between 5 mm and 7 mm thick rotor disc a small difference in EMF waveform magnitude exists. On the other hand, there is practically no difference between the EMF waveform magnitude when using the rotor disc thicknesses of 7 mm or 11,6 mm.

Influence of rotor thickness on magnetic field distribution by armature current

Figures 14, 15, 16 and 17 present normal component of magnetic flux density distribution due to the armature current of 10 A without PM excitation at the PM centre along the axial direction through the whole machine model at the different rotor disc thicknesses (D):

- 3 mm in Fig. 14;
- 5 mm in Fig. 15;
- 7 mm in Fig. 16;
- 11,6 mm in Fig. 17.

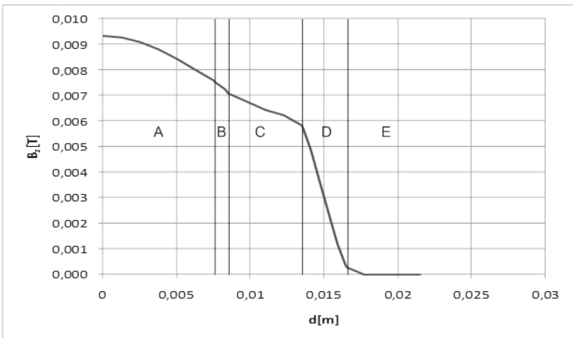

Fig.14. Normal component of magnetic flux density distribution (rotor disc thickness is 3 mm)

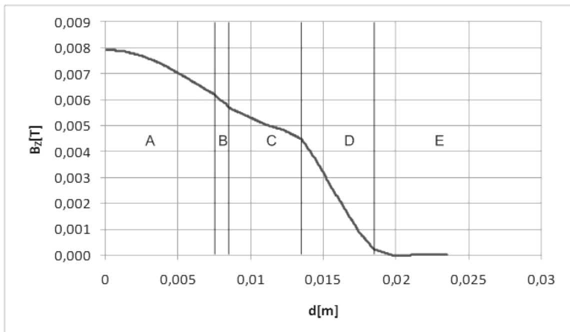

Fig.15. Normal component of magnetic flux density distribution (rotor disc thickness is 5 mm)

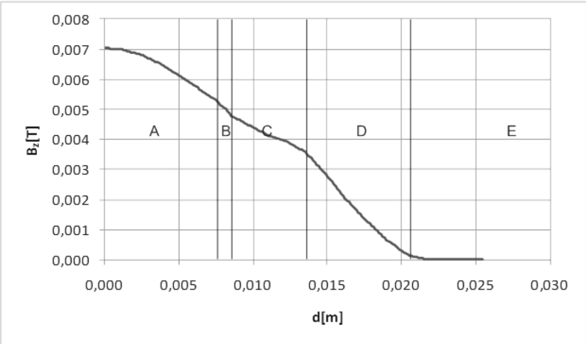

Fig.16. Normal component of magnetic flux density distribution (rotor disc thickness is 7 mm)

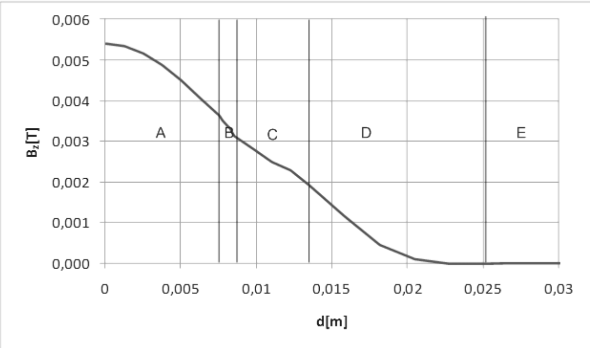

Fig.17. Normal component of magnetic flux density distribution (rotor disc thickness is 11,6 mm)

Influence of rotor thickness on magnetic field distribution by armature current and permanent magnets

Figures 18 and 19 present instantaneous normal component of magnetic flux density distribution due to the armature current of 10 A and PM excitation at the PM centre along the axial direction through the whole machine model at the rotor disc thickness 5 mm and 11,6 mm, respectively.

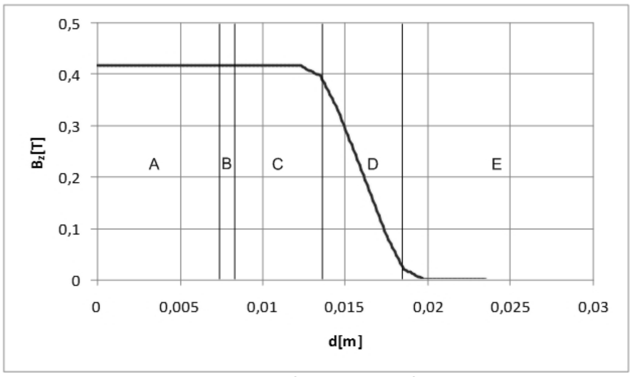

Fig.18. Normal component of magnetic flux density distribution (rotor disc thickness is 5 mm)

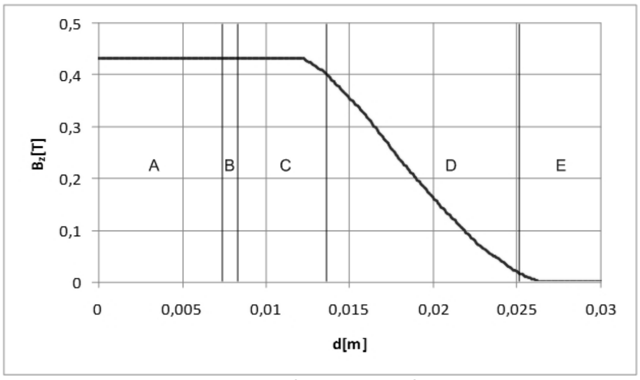

Fig.19. Normal component of magnetic flux density distribution (rotor disc thickness is 11,6 mm)

Conclusion

Normal component of magnetic flux density (Fig. 5) confirms the conclusions based on the results in Fig. 13, because there is practically no difference between magnetic flux density magnitudes calculated at 7 mm and 11,6 mm of rotor disc thickness. It can be seen that between 5 mm and 7 mm thick rotor disc a small difference in EMF waveform magnitude exists and that there is practically no difference in the EMF waveform magnitude when using the rotor disc thickness of 7 mm or 11,6 mm.

On the basis of EMF waveform magnitude for the rotor disc thickness of 3 mm it can be concluded that from magnetic point of view rotor disc should not be thinner than 5 mm, but it is preferred to be 7 mm. From the mechanical point of view a new problem arises due to the large attractive forces between both rotor discs of double sided AFPMSM. These forces deform the rotor disc. In the future work it should be verified the bending of the rotor discs at different rotor disc thicknesses.

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