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APPLICATION OF PERMANENT MAGNETS WITH MULTI-DIRECTIONAL MAGNETIZATION IN MAGNETOELECTRIC DISC MOTOR

Abstract: Electrical machines are increasingly being employed in electric drives, among other things in car industry (ecological cars) and aerospace sector. In these drives, in order to increase the dynamics of the electric drive moment of interia should not be a large value. The mass of motor is one of the factors influencing the moment of interia. This paper deals with the axial flux permanent magnet (AFPM) motor. The structure of the motor is the following: disc type, inner coreless stator with windings in segmented electromagnetic array (SEMA) technology. In such electric motors the decrease of their mass can be obtained by the decrease of back iron thickness. The reduction of back iron thickness in disc motor can be attained by application of permanent magnets with multi-directional magnetization (permanent magnets arranged in Halbach array). The paper presents the results of simulation researches of the influence of application of permanent magnets (PMs) with multi-directional magnetization on magnetic flux density distribution in back iron of magnetoelectric disc motors.

1. Introduction

Magnetoelectric machines found wide application and are of great importance in drives at present. It should be stressed that classical induction and synchronous motors are not suitable for driving certain equipment. It is the case when low rotation speed or constant speed at varying load torques high dynamics is required or when no mechanical gears can be used [1]. Therefore the magnetoelectric machines find application in automation (servo-drivers in industrial robots), in aircraft industry and in case when drives of high dynamics as well as minimum volume and mass of motor are required [2, 3]. Significant range of such motor applications can be seen now in car industry as direct drive (so called ecological cars) [4, 5].

Design of magnetoelectric machines with cylinder structure as well as disc structure are still developed [6, 7]. The aim is to obtain highest powers per unit, electromagnetic torque, efficiency and dynamics with, at the same time, reduced torque pulsation, motor mass and volume, with power and torque retained at a constant level.

In motors with increased dynamics, the moment of interia should be as low as possible. In comparison with cylinder structure of motors the disc type ones are characterized among others by lower dimensions, higher power density and advantageous power to mass ratio [8]. The paper discusses minimization of mass of disc type magnetoelectric motor intended for vehicle drive.

2. Investigated model of disc motor

The aim of the investigations presented in this paper was determining of the influence of application of PMs with multi-directional magnetization on magnetic flux density distribution in back iron and in air gap of magnetoelectric disc motors. The magnetoelectric disc motor with internal coreless stator and with two external rotors was considered. The cross section of the investigated motor is presented in Fig. 1. The parameters characterizing the motor are presented in Table 1 [9].

Application of coreless constructions and windings SEMA technology in disc motors allow not only to eliminate the stator's cores, but also to increase its efficiency, decrease weight and size. Application of coreless constructions allow to eliminate pulsation of electromagnetic torque and hysteresis losses [10].

In the motor structure as in Fig. 1 a big share in its mass have the rotor yokes (1 in Fig. 1), especially in case of low number of pole pairs. Reduction in their thickness as a result of applying PMs with multi-directional magnetization (according to the Halbach array) would allow to reduce the motor mass and its moment of interia significantly.

In references [11, 12, 13] there appear test results of brushless DC motors with PMs with multi-directional magnetization. The main aim of such magnet system is obtaining a sinusoidal distribution of the magnetic flux density in the machine air gap applying a suitable control method [14]. In brushless DC motors with PMs the principal problem are pulsation of the electromagnetic torque. The dominant component of these pulsations is the cogging torque. One of the ways of limiting the amplitude of the cogging torque is application of PMs with multi-directional magnetization (according to the Halbach array) [1, 8, 11, 12, 13, 14].

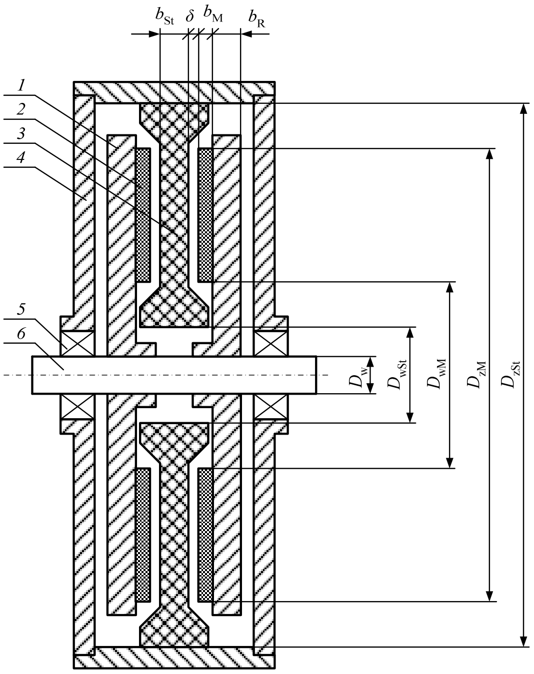

Fig.1. Basic topologies of AFPM motor with internal stator: 1 – rotor yoke, 2 – permanent magnet, 3 – stator winding, 4 – frame, 5 – bearing, 6 – shaft

Tab.1. Parameters of the investigated disc motor

Sym.	**Parameter**	**Value**
D_{zSt}	Ext. diameter of stator [mm]	250.0
D_{wSt}	Int. diameter of stator [mm]	105.0
D_{zM}	Ext. diameter of PMs [mm]	220.0
D_{wM}	Int. diameter of PMs [mm]	127.0
D_W	Diameter of shaft [mm]	40.0
b_{St}	Thickness of stator [mm]	8.0
δ	Thickness of air gap [mm]	1.5
b_M	Thickness of PMs [mm]	6.0
b_R	Thickness of stator yoke [mm]	10.0
$2p$	Number of poles	6
I_f	Nominal current [A]	12.5
m	Number of winding phases	3
α_M	Magnet arc length [° el.]	160.0

Application PMs with multi-directional magnetization in disc motor as shown in Fig. 1 causes the magnetic flux density in back iron to be reduced. The magnetic flux closes practically inside the ring of magnets. Such a structure of motor permits to reduce the yoke thickness (1 in Fig. 1) and by this to reduce the motor mass and moment of interia.

3. Results of simulation researches

The numerical calculations of distribution of magnetic flux density in the disc motor in three dimensional space were made. The magnetostatic field was analyzed. Two models of disc motor were investigated: with PMs magnetized in classical way (magnetized axial) with magnet arc length equal to 160 ° electrical and model of PMs disc motor with sub divided each its pole into a number of equal arc segments where the direction of magnetization of the segments are alternately orientated normally and tangentially to the magnet surface. In Fig. 2 the models of the investigated disc motor are presented.

The model of a motor with PMs arranged in discrete Halbach array has two segments per pole. Fig. 3 presents a Halbach array formed from discrete segments of a PM (in Cartesian coordinate system). Every segment of PMs in model of motor has equals arc and equals to half pole pitch.

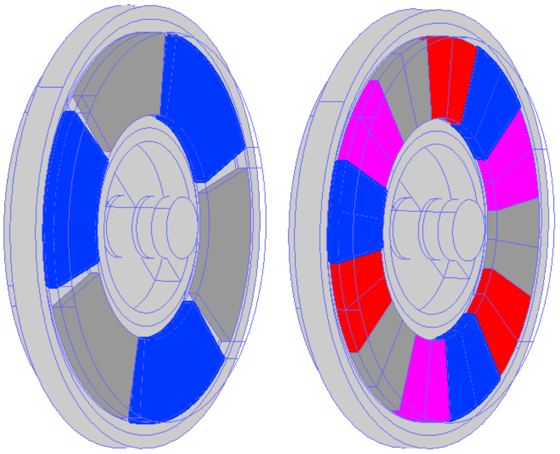

Fig.2. Models of AFPM motor: with PMs magnetized classically and magnet pole arc equal to 160 ° electrical (left); with PMs sub divided into a number of equal arc segments where the direction of magnetization of the segments are alternately orientated normally and tangentially to the magnet surface (right)

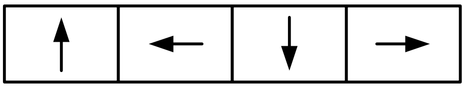

Fig.3. Halbach array formed from discrete segments of permanent magnet (two segments per pole)

The numerical calculation results are presented in Figures 4 to 13. From this point of view there is a not large difference between the numerical calculation results obtained taking only PMs as a magnetic field source into consideration and taking armature reaction into consideration (nominal value of current $I_f = 12.5$ A), the results for the first case are presented in the paper. The values of components of magnetic flux density in the air gap (figures 6 and 10) are determined in half of thickness of air gap and in half of height of PMs. Three dimensional distributions of magnetic flux density were determined in surfaces limited by models width b ($b = 2*(b_R + b_M + \delta) + b_{St}$, symbols as an Fig. 1), being located between a center of one pole pitch ($\alpha = 30$ °, Figures 4 and 5) and a center of next pole pitch ($\alpha = 90$ °) and being located in three heights: $D_{wM}/2$ – in the lower edges of magnet surface, $D_{wM} + 0.5*(D_{zM}/2 - D_{wM}/2)$ – in the surface in center of height of magnets, $D_{zM}/2$ – in the upper edges of magnet surface.

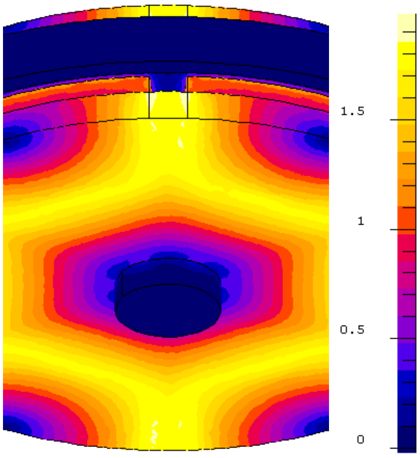

Fig.4. Distribution of magnetic flux density in the disc motor with PMs magnetized classically

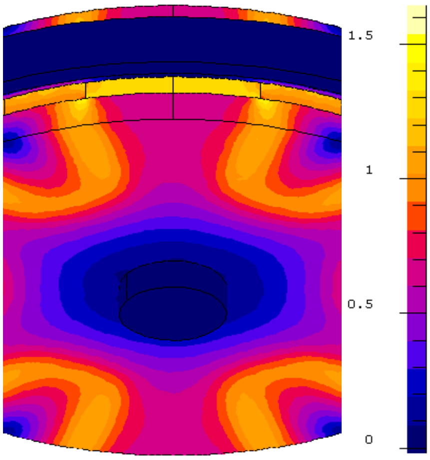

Fig.5. Distribution of magnetic flux density in the disc motor with PMs arranged in discrete Halbach array

In magnetoelectric motor with PMs with multidirectional magnetization with cylinder structure as well as disc structure there are used constructions with magnetized segments connected by glueing or magnets are used in form of magnetized ring [15]. The second case was assumed in numerical calculations of distribution of magnetic flux density in the disc motor with PMs arranged in discrete Halbach array.

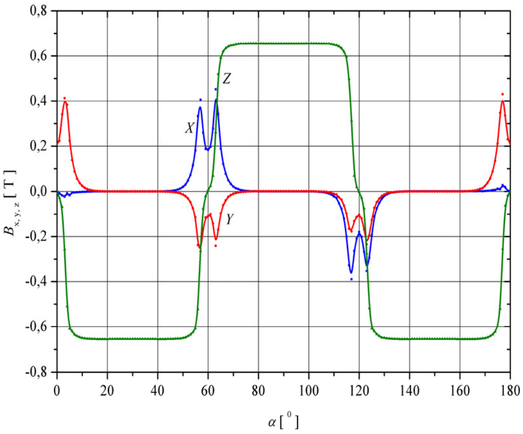

Fig.6. Distribution of components of magnetic flux density in the disc motor with PMs magnetized classically

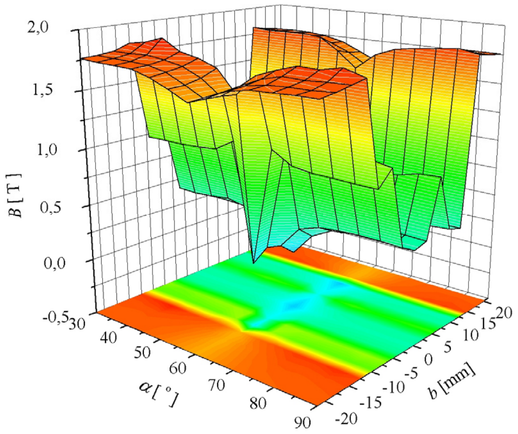

Fig.7. Distribution of magnetic flux density in the disc motor with PMs magnetized classically in the lower edges of magnet surface

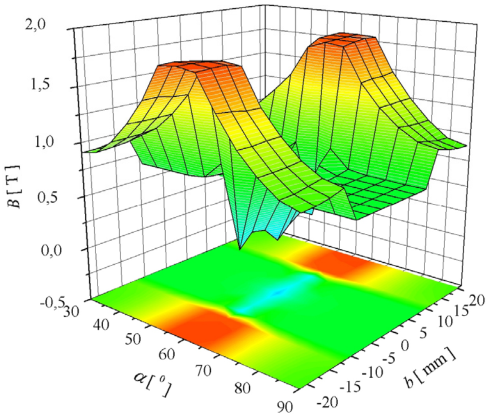

Fig.8. Distribution of magnetic flux density in the disc motor with PMs magnetized classically in the surface in the center of height of magnets

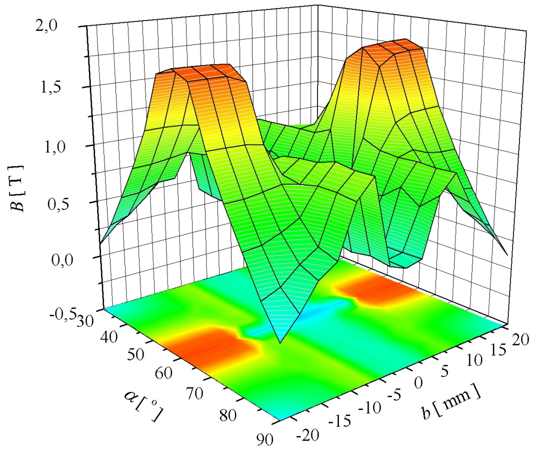

Fig.9. Distribution of magnetic flux density in the disc motor with PMs magnetized classically in the upper edges of magnet surface

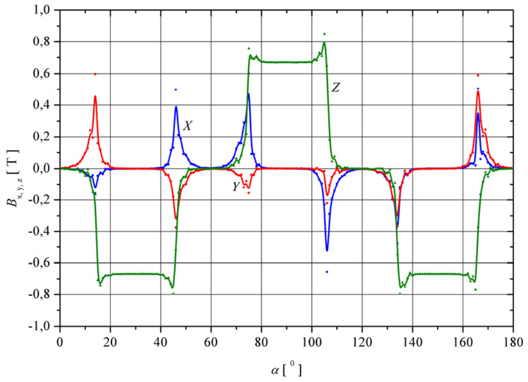

Fig.10. Distribution of components of magnetic flux density in the disc motor with PMs arranged in discrete Halbach array

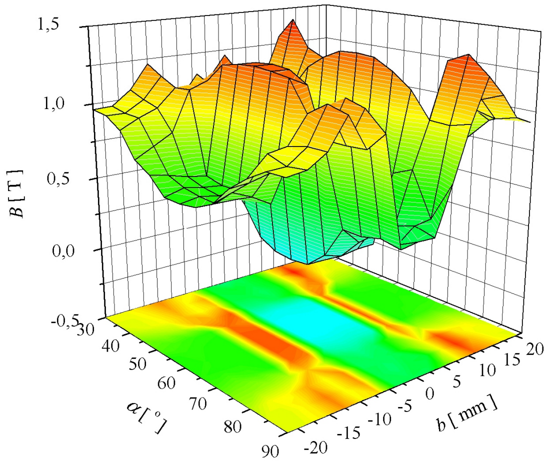

Fig.11. Distribution of magnetic flux density in the disc motor with PMs arranged in discrete Halbach array in the lower edges of magnet surface

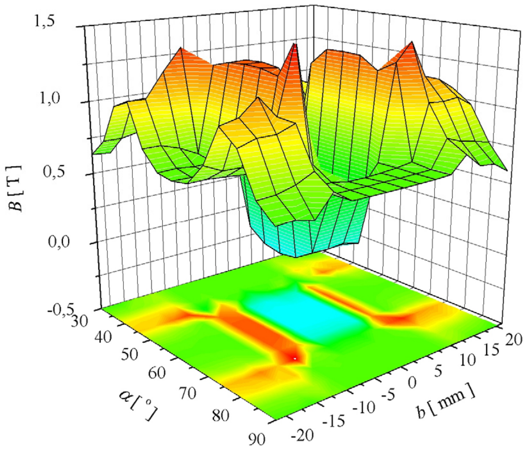

Fig.12. Distribution of magnetic flux density in the disc motor with PMs arranged in discrete Halbach array in the surface in the center of height of magnets

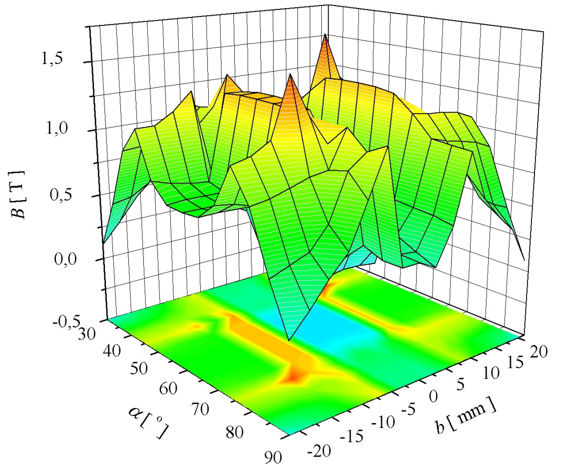

Fig.13. Distribution of magnetic flux density in the disc motor with PMs arranged in discrete Halbach array in the upper edges of magnet surface

4. Summary

The following conclusions are presented basing on simulation test results:

1. symmetrical distribution of magnetic flux density in the considered disc motor were obtained (Figures 4 and 5),
2. application of PMs arranged in discrete Halbach array (with the same geometrical dimensions of the disc motor model) did not cause any significant changes in values of magnetic flux density in air gap both at excitation from PMs as well as with armature reaction considered (nominal value of current $I_f = 12.5$ A); change in variation of the components curves of flux density in the disc motor with PMs arranged in Halbach array, results from arrangement of magnets; the average value of flux density in the air gap is within 0.65 and 0.70 T,
3. application of PMs arranged in discrete Halbach array with the same geometrical dimensions of the disc motor model in comparison to disc motor model with PMs magnetized classically caused significant changes of distribution and values of the magnetic flux density in the back iron both at excitation from PMs as well as with armature reaction considered: with only the PMs considered (as the magnetic field source) the maximum value of flux density module in the motor back iron with PMs magnetized classically at the height of the magnet lower edges surface is 1.76 T, at the half of magnet height and at the magnet upper edges surface it is 1.92 T, while in the motor back iron with PMs magnetized according to Halbach array the corresponding values are respectively – 1.18 T at the height of the magnet lower edges surface and 1.31 T at the half of magnet height and at the magnet upper edges surface,
4. reduction in the magnetic flux density value in rotor yoke as a result of applying PMs arranged in Halbach array permits a lower rotor yoke thickness b_R (1 in Fig. 1) to be adopted which causes reduction in the motor mass and moment of interia.

The simulation test results for a disc motor with PMs arranged in discrete Halbach array included in par. 3 of the conclusions in Authors opinion are overstated. The simulation test results presented will be compared with results obtained when considering other conditions of magnetization according to Halbach array, that is for different directions of magnetization vectors within the range of one pole and with different angular width of segments. The obtained results will also be compared with experimental test results in physical model of disc motor.

5. Bibliography

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