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DISK STEPPER MOTOR WITH PERMANENT MAGNETS

Abstract: The brushless machine with axial flux and permanent magnets (AFPM), also called the disc-type machine, is an interesting alternative to its cylindrical radial flux counterpart due to the disk shape, compact construction and high torque density. AFPM disk motors are particularly suitable for electrical vehicles, robots, valve control, pumps, centrifuges, fans, machine tools and manufacturing. The first parts of the paper compare of drive system with disk-motor to the motor with cylindrical shape, as well as disk-motor with radial and axial flux. Next part of the contribution describes types of the disk motors and their construction. The 3D magnetic simulation and analysis of the disk stepper motor with permanent magnets is being subject of the article, too. The unique disc-type profile of the rotor and stator of AFPM machines makes it possible to generate diverse and interchangeable designs. AFPM machines can be designed as single air gap or multiple air gaps machines, with slotted, slotless or even totally ironless armature. Low power AFPM machines are frequently designed as machines with slotless windings and permanent surface magnets.

1. Introduction

The disk stepping motors, like cylindrical stepping motors, can be viewed as brushless machine. Typically, all windings in the motor are part of the stator, and the rotor is either a toothed block of some magnetically soft material, in the case of variable reluctance motors, or the permanent magnet (PM).

The progress in power electronics and drop in prices of rare-earth permanent magnet materials have played an important role in the development of PM brushless machines in the last three decades. These machines have recently become mature and their high efficiency, power density and reliability have led to PM brushless machines successfully replacing the d.c. commutator machines and cage induction machines in many areas.

The brushless machine with axial flux and permanent magnets (AFPM), also called the disc-type machine, is an interesting alternative to its cylindrical radial flux counterpart due to the disk shape, compact construction and high torque density. The power range of AFPM brushless machines is now from a fraction of a watt to sub-MW.

Disc-type rotors can be embedded in power-transmission components or flywheels to optimize the volume, mass, number of parts, power transfer and assembly time. For electric vehicles with built-in wheel motors the advantage is a simpler power train, higher efficiency and lower cost. Dual-function rotors may also appear in pumps, elevators and other machinery, bringing added values of performance to these products.

2. Advantages and Disadvantages of Stepper Motor

When using a stepper motor it must be know the motor advantages and disadvantages. The main advantages of stepper motor are:

- Rotation angle of the motor is proportional to the input pulse.
- A wide range of rotational speeds can be realized and is proportional to the frequency of the input pulses.
- It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.
- Correct positioning and repeatability of movement since stepper motors have an accuracy of 3 – 5% of a step.
- The error of a step is non cumulative from one step to the next.
- If the windings are energized the stepper motor has full torque at standstill.
- Excellent response to starting/stopping/ reversing.
- The motor is very reliable since there are no contact brushes in the motor. The life of the motor is therefore dependent on the life of the bearing.
- The motors response to digital input pulses provides open-loop control. The production of the motor is simpler and to control is less costly.

The main disadvantages of stepper motor are:

- The stepper motor have limited speed (limited by torque capacity and by pulse-missing problems due to faulty switching systems and drive circuits)

- Not easy to operate at extremely high speeds.
- The resonances can occur if not properly controlled.
- The resonance effect of a stepper motor comes from its basic construction.
- This can be seen as a sudden loss or drop in torque at certain speeds which can result in missed steps or loss of synchronism. It occurs when the input step pulse rate coincides with the natural oscillation frequency of the rotor.

3 General analysis of the disk motor

Electrical disk machines have been designed, constructed and improved by several decades. Practically there is one group of electric machines, where the air gap is vertical to the axis of rotor rotation, then magnetic flux cause in the direction of axial, it comes to this, that parallel with rotating axle. These machines called also as machines with axial magnetic flux. Fig.1 shows the difference between arrangement of radial and axial magnetic flux. The rotor these machines is made in form of disk and it is regard, that practically is used to name „disk motors". Because of heightening torque these disk motors mostly have double stator, what divides the air gap into two parts.

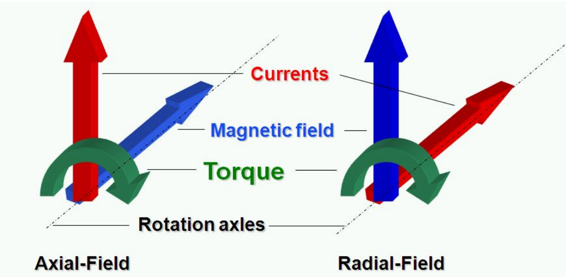

Fig.1. Principled difference between axial and radial magnetic flux

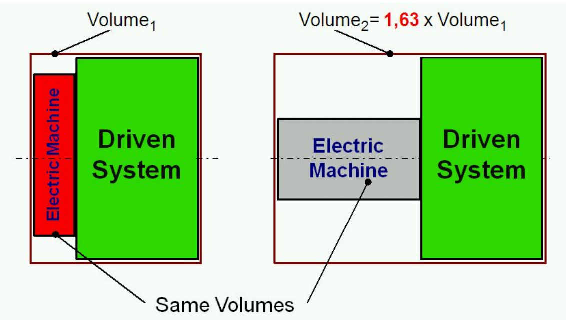

Fig.2. Comparison of total volume drive with disk and cylindrical motor

The drive systems with motors of disk shape in comparison to the motors of cylindral structure have some fundamental advantages [1]. One of the main advantages of disk motor is small axial length. Between primary advantages belong a smaller volume of full drive at equal power in instance of disk motor (Fig. 2).

However, if we compare a power of disk motor with axial magnetic flux with power in whatness of same disk motor, but design solution like this, but with so much design solution, that magnetic flux flows in radial direction, so at holdback about equally of volume, the power of the motor with axial magnetic flux is ca. more than 50% higher than the power of the motor with radial magnetic flux (Fig. 3).

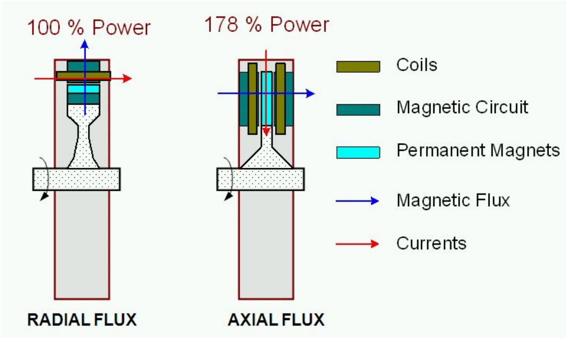

Fig.3. Comparison of disk motor power with radial and axial magnetic flux

4 Construct modifications of disc motors

In general we can of disk motors divided according to a number of criterions. According to method power supply divided the disk motors with axial magnetic flux:

- disk motors continuously power supply,
- disk motors pulse-wise power supply.

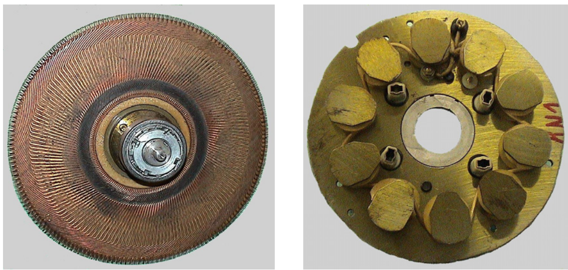

Fig.4. The rotor and stator of DC disk motor

Continuously power supply disk motors can divided, much like a classic motors, in DC and AC disk motors and AC disk motors divided in asynchronous and synchronous. DC low power disk motors are produced generally with permanent magnet excitation and have fundamentally a different design as cylindrical DC motors. Both

constructions are described in [1]. In foretime most widely used armatures of DC disk motors have had a shape of disk at what is e.g. pressed a winding and is applied permanent magnet excitation. Permanent magnets are placed at the stator on either side of armature (Fig. 4).
Newer constructions of disk motor with axial magnetic flux with permanent magnet have [1] two designing variants feasible solution (Fig. 5):

- the winding motor with iron core,
- the winding motor with ironless core.

The permanent magnets are generally in rotor inserted. Motor with PM and winding with iron core (Fig.5-left) has rotor, which is between by two of stators located. Coils are on stator poles located.

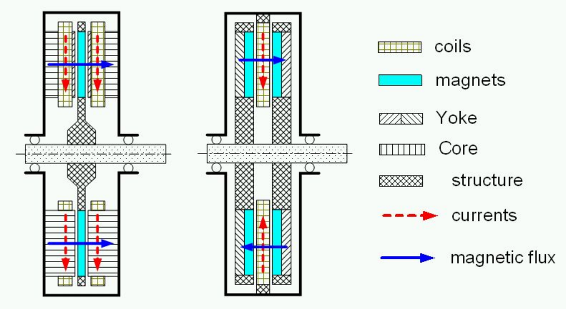

Fig.5. Construction of disk motor with axial magnetic flux and PM

Coils in one phase are connected in series and are winding conformable. The current flows of coils in one phase of single-direction. The magnetic flux has in all two coil and them corresponding segments from permanent magnet of one phase same orientation. Motor with PM and winding with ironless core (Fig.5-right) is of similar construction as the motor with iron core, but the stator is only one and the stator is situated between double rotor. Coils in one phase are winding non-conformable. Currents flow of corresponding coil in power supply phase bleeding "into machine" and thereby magnetic flux in every coil is enclosed in opposite sense.

5. Disk stepper motor with permanent magnets

Disk stepper motors are permanent-magnet motors that exhibit performance comparable to that of hybrid motors. Rotors in disk motors are thin (typically less than 1-mm) disks, unlike the cylindrical rotors in hybrids and conventional permanent-magnet motors. The disc motors are generally a little over half as big as hybrid motors of equal power output and weigh 60% less [2]. The disk motors are still frequently used for their low inertia and high torque. Recent improvements include neodymium magnets and power ratings up to 250 W for industrial-grade motors.
The disk stepper motors with axial magnetic flux and permanent magnets are recently out of manufacturer interest that reflects minimal number of firms active in production and distribution of this group of machines. This motor construction is selected in specific applications, determined e.g. by the disposal volume for motor. Company Portescap [3] offers one of the broadest miniature motor product lines in the industry, encompassing also disc magnet stepper motor (Fig. 6).

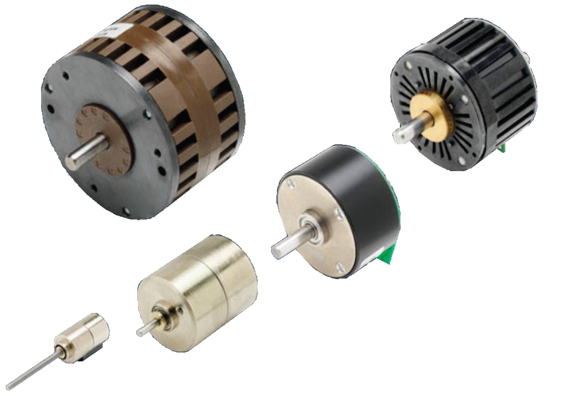

Fig.6. TurboDisc™ Stepper Motors with PM

Figure 7 shows the principle of a disk magnet motor developed by Portescap.
Brushless disc motors (but no stepper) product the company Baumüller [4]. The main strengths of Baumüller disc motors are that they are compact and flat. In their shortest design, only 36.5 mm of axial space is required.

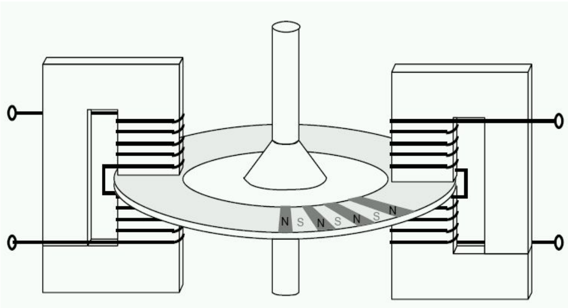

Fig.7. Principle of a disk magnet motor developed by Portescap

DSM 115 - 190 - Brushless Disc Motors have Special Compact and flat design as high-torque drive for low and medium powers up to 6300 W (Fig. 8).

Fig.8. Brushless disc motors by Baumüller

Brushless disc motors are manufactured according to two different principles:

- for the lower power range the ironless winding slips from the rotor into the stator and the magnets slip from the stator into the rotor, where they can be built onto the rotating magnetic feedback directly,
- for the higher power range the stator winding is inserted into the slotted armature with skewed stacks and the power output can be considerably increased thanks to the smaller magnetic air gap used in this method.

Fig.9. Disk Stepper Motor with PM by Sinotech

The third some known producer of disk stepper motors with permanent magnets (Fig. 9) is also the company Sinotech. Sinotech motors [2] are engineered in the U.S. and manufactured in China.

6. Electromagnetic field simulation of disk stepper motor with PM

For comparison Fig. 10 shows the model of magnetic circuit disk stepper motor without PM and on Fig. 11 is displayed the simulation of electromagnetic field.

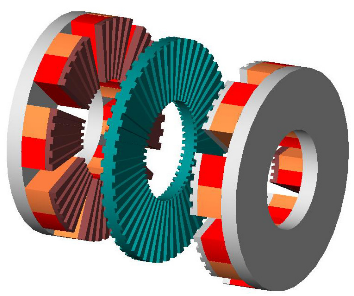

Fig. 10. Magnetic circuit of disk stepper motor without PM

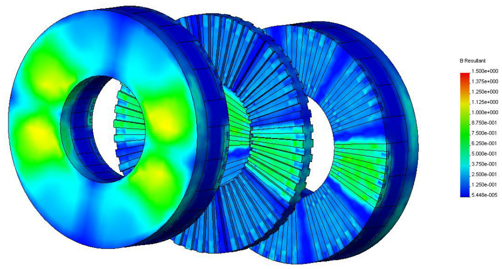

Fig.11. The electromagnetic field of disk stepper motor without PM

Fig. 12 shows a model of the magnetic circuit of disk stepper motor with PM, that is examinant below.

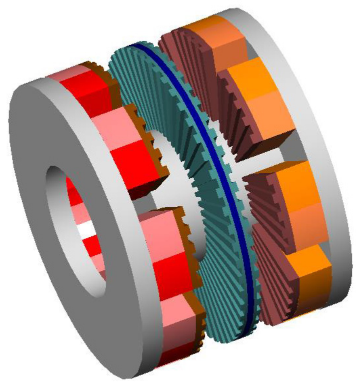

Fig. 12. Magnetic circuit of disk stepper motor with PM

This motor belong to a group construction with two separate opposite stators. The stator yoke is toroid. On toroid is eight slotted pole, on that is wound coil. Motor has a four phase. The every phase is always two opposite coil of one stator and opposite coils of two stator creating, consequently together four coils. The rotor structure is formed by toroidal axially magnetized permanent magnet and rotor slotted yoke.

The 3-d model of electromagnetic circuit is created in a program ProEngineer. The simulation of electromagnetic field is made in a program Cosmos/EMS. Maxwell's equations relevant to magnetostatic analysis fields are:

$$\nabla \times H = J_s \qquad \nabla \cdot B = 0 \qquad [1]$$

where H is the magnetic field, J_S is the source current density, and B is the magnetic flux density. The constitutive relation connects B and H:

$$B = \mu(H + H_C) \qquad [2]$$

where μ is the magnetic permeability, in general a function of H. H_C is the coercive force in (A/m).

As boundary conditions the tangential flux is used. While simulation is all model of the electromagnetic circuit containerized of an air. The parameters used about simulation:

- global element size: 5,3678mm; mesh control was used on the rotor and air gaps,
- total nodes: 27122,
- total elements: 152989,
- mesh type: standard.

The simulation of electromagnetic field disk stepper motor with PM is shown in Fig.13 and Fig.14.

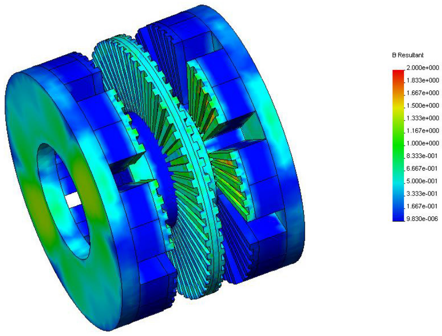

Fig. 13. The electromagnetic field of disk stepper motor with PM

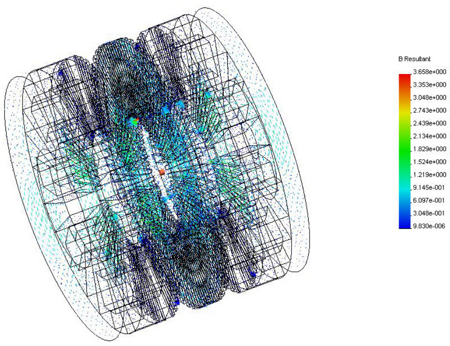

Fig. 14. The electromagnetic field of disk stepper motor with PM

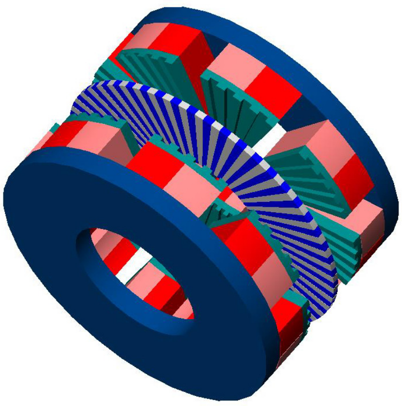

Fig. 15. Magnetic circuit of disk stepper motor with PM disk rotor without iron yoke

The stepper motor with axial flux permanent magnet disc-type non-slotted internal-rotor and two slotted external-stators was too simulated. This machine can be designed for higher torque-to-weight ratio and higher efficiency and can be considered as a significant advantage over conventional PM machines.

The rotor structures of this machine is formed by the axially magnetized surface magnets without iron yoke. Fig. 15 shows a model of the magnetic circuit of disk stepper motor with PM, which is described above.

The flux then travels circumferentially along the stator core, returns across the air gaps, and then enters the disk rotor through the opposite polarity of the magnets.

It should be mentioned that the portions between the permanent magnets in nonslotted topologie of disk rotor are filled with epoxy resin so as toform a solid rotor structure and increase the robustness of the rotor.

Fig. 16 shows of density meshes at simulation. On the right is air, that is at simulation hidden.

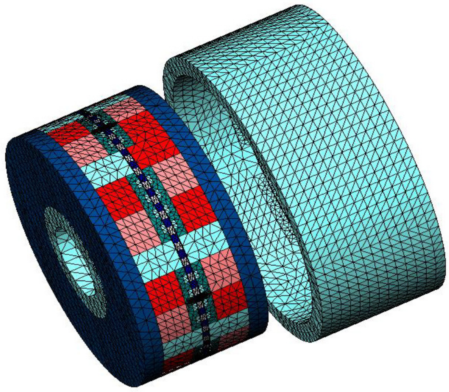

Fig. 16. The meshes at simulation

The simulation of electromagnetic field disk stepper motor with PM disk rotor without iron yoke is shown in Fig.17 and Fig.18.

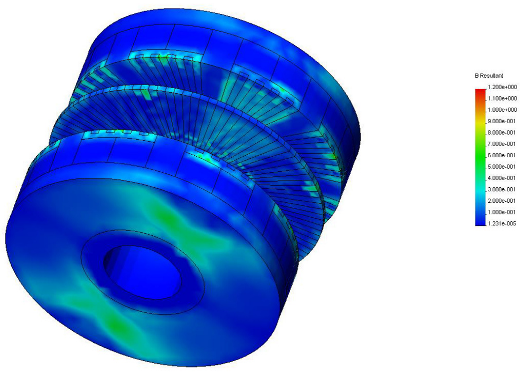

Fig. 17. The electromagnetic field of disk stepper motor with PM disk rotor without iron yoke

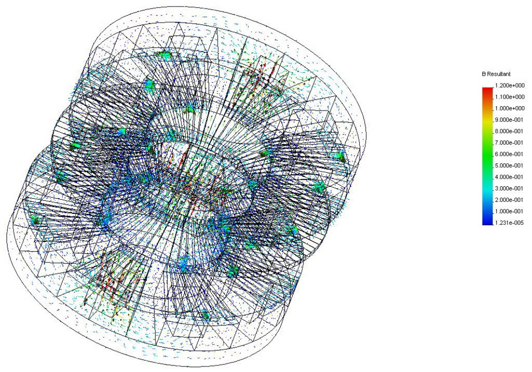

Fig. 18. The electromagnetic field of disk stepper motor with PM disk rotor without iron yoke

7. Conclusion

The disk stepper motors are ideally suited for measurement and control applications. The step resolution and performance of these motors can be improved through a technique called microstepping and used to disk rotor with permanent magnets. This paper has described the comparison and the first results of simulations electromagnetic field in PM disk stepper motor with various disk rotor design.

8. Acknowledgement

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