Design And Analysis Of Brushless DC Motor With Magnetic Powder Core And Nd-Fe-B Bonded Magnets

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Abstract

The main aim of the work is to design and manufacture a model of brushless DC motor (BLDC) with magnetic circuit made of magnetic powder bonded in solid material by powder glue. Soft magnetic elements manufactured in this method are called soft magnetic composites or dielectromagnetics, permanent magnets are called bonded magnets or dielectromagnets. In this paper design and computer's analysis of this motor are presented. Model of motors will be manufactured and measured in the next step of work.

1. Introduction

Nowadays in household equipment such as vacuum cleaners, mixers, food processors and juice extractors single phase electric motors with a commutator and a series excitation are used. This kind of electric motor has a lot of disadvantages such as excessive noise, low efficiency up to about 50% and short period of operational use because of commutator and brush wear out. These disadvantages can be eliminated by application of brushless DC (BLDC) motors with composite hard and soft magnetic circuits. Brushless DC motors with electronic supply system have efficiency up to 90%. Additional advantage of brushless DC motor with a cylindrical permanent magnet instead of series of magnets is better construction allow to eliminate problems with tearing off permanent magnets from the rotor at high rotational speed.

The main task of the work is to design and analyze brushless DC motor with iron magnetic powder core and Nd-Fe-B bonded magnets. It is according with direction of research carried out in research centers working on new constructions of electric motors [1,2]. In design process it is assumed that powder magnetic core will be made of iron powder bonded by epoxy glue. As a permanent magnet in motors Nd-Fe-B bonded magnet will be used. Soft magnetic core in model motor will be comprised from units such as poles, pole pieces, and stator core. It will reduce cost of manufacture of a stator. In production process stator could be manufactured as a one part.

This type of brushless DC motors could be applied in different household equipment. In the development of new brushless DC motor with powder magnetic circuits units, such as bearings, supporting plastic and metal elements and screws, from electric motors in production are utilized. It is connected with many limitations for example overall dimensions of motor in series production. Nominal output power of motor must be 250W and nominal speed 6000 rpm, minimum speed 5000 rpm and maximum speed 15000 rpm.

Model brushless DC motor will be equipped with commercial electronic commutator with Hall sensors.

2. Brushless DC motor with electronic supply system

Brushless DC motors (BLDC) with electronic supply system is one of highest energy efficient electric motor and has one of highest power in terms of weight or volume of a motor. BLDC motors are also very durable due to lack of mechanical commutator and brushes. Life limit of a machine is mainly matter of bearings. This type of motor usually has a stator with three phase windings and a rotor made of solid steel with permanent magnets. BLDC electric motor is also equipped with an encoder to determine position of a rotor's permanent magnets in relation to windings with electric currents.

This type of motor requires electronic converter which supplies electric motor. There are two types of brushless motors – with sinusoidal or trapezoidal back electromotive force and current courses. First electric motor is called permanent magnet synchronous motor (PMSM), second permanent magnet brushless DC motor (BLDC). Both motors are supplied with alternating voltages and currents. BLDC motor is called DC motor because operation and mathematical equations describing motor are similar to DC motor with brushes [3,4]. In BLDC motor current flows through two phases in the same moment in first phase with sign "+", in second phase with sign "-", whereas in 3 phase PMSM through three phases as in induction motor. For example for specific moment for permanent magnet synchronous machine in one phase it is I_m in rest two ($-0.5I_m$).

Electronic converter for brushless DC motor is also called electronic commutator. It usually comprise of power transistors as a switching elements in electric circuit of windings of a motor. Electronic commutator also is equipped with electronic device to control flow of currents in windings. Usually it is PWM method – pulse width modulation. Commercially available electronic commutator has DC input and has three phase output with controllable frequency of currents. Frequency of current is deciding about regulation of speed of a rotor. Commercially available electronic commutators have DC supply voltage up to 70V and current up to 30A. In order to ensure rotation of a rotor of a motor in commercial electronic commutator there is inputs from position encoders. Encoders can be optoelectronic or magnetic. Usually optoelectronic encoder comprise of source of light and detector and disc with slots. Magnetic encoder comprise of multi-pole permanent magnets and Hall sensors.

In investigation rectifier with output voltage 48V and commercial electronic commutator is planned to use with model brushless DC motor. In case of production this kind of motor electronic equipment has to be designed. It allows to reduce cost of supply system.

2.1 Magnetic circuit in brushless DC motor

Magnetic circuits in electric machines comprises of soft magnetic materials with coils. In magnetoelectric motors there is also multi-pole permanent magnet or there are two pole permanent magnets. Electric current in coils generates magnetic flux in a core. Magnetic flux can be also generated by permanent magnets. In rotating electric machines influence of magnetic flux generated in stator and rotor causes generation of electromagnetic torque and movement of a rotor.

Soft magnetic parts of magnetic circuit are made mainly of electrical steel. Permanent magnets are executed mainly from sintered powders of hard magnetic ferrite.

2.1.1. Soft magnetic composites

Soft magnetic parts of magnetic circuit are more often produced from iron soft magnetic powders bonded by epoxy resin. Magnetic powder is compressed in a form of desired shape of a core. This technology is almost without waste of material in production and is friendly in recycling. Process of compression increases density of magnetic elements and enhances magnetic and mechanical properties of a core. Epoxy resin bonds magnetic powder and allow to obtain high electrical resistivity of a core due to insulation of iron powder grains by dielectric resin. High resistivity of magnetic core is essential when electric motor works with higher frequency of magnetic flux.

2.1.2. Nd-Fe-B bonded permanent magnets

Permanent magnets from Nd-Fe-B powder are more and more used in electric machines. Hard magnetic powder from Nd-Fe-B melt-spun ribbon is used as a starting material to this type of bonded magnets. Hard magnetic powder is also bonded by epoxy resin and has high electrical resistivity. Bonded magnets used in design stage are isotropic and can be magnetized in various directions with two or more magnetic poles.

3. Design of brushless DC motor with powder magnetic circuits

According to analytical methods brushless DC motor has been designed. Analyses of the motor and its performance were conducted using commercial software Opera 3D.

Brushless DC motor will have three phase, four-pole permanent magnet, and stator with six pole pieces. Each phase consists of two concentric coils placed on rounded pole body. Rounded poles decrease length of winding and decrease leakage flux. Designed motor is presented in fig. 1. In fig. 1 there is presented motor only with one phase because rest of motor could not be seen clearly. The electric motor has two grooves in stator joke for screws used for housing with bearings.

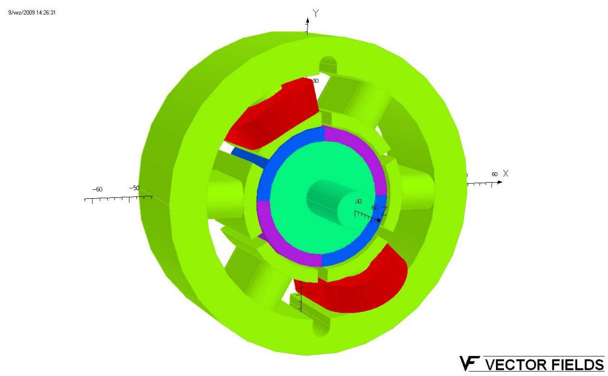

Fig.1. Brushless DC motor.

Dimensions and parameters of designed motor are presented in table 1.

Tab.1.

Dimensions and parameters of brushless DC motor

Outer stator diameter	87 mm
Inner stator diameter	39.4 mm
Axial length of stator	30 mm
Outer rotor (magnet) diameter	38 mm
Inner magnet diameter	31 mm

Axial length of rotor	28 mm
Thickness of stator's core	10 mm
DC supply voltage	48 V
DC supply current	6.5 A
Stator material - SMC	Iron-resin composite Somaloy 500
Maximum permeability of SMC	200
Number of phases and type of connection	3, star
Number of poles	4
Type of permanent magnet	Nd-Fe-B bonded magnet
Magnetic parameters of permanent magnet	B_r=0.65 T H_{cB}=430 kA/m H_{cJ}=1250 kA/m BH_{max}=70kJ/m^3

4. Analysis of brushless DC motor with powder magnetic circuits

Finite element methods are widely used in analyses of electric motors. These methods allow to analyze electric motors in a design stage and reduce costs of manufacturing series of models of electric machines. These finite elements methods were used, between others, for 2D analyses of transient states such as starting process of magnetoelectric motors with a semiconductor converter [5] or 3D analyses of steady state of magnetoelectric brushless motor with double cylindrical rotor supplied with sinusoidal currents [6].

Computer's calculations were performed using commercial software Opera 3D version 10.535 from Vector Fields Company. This application is based on finite element method. In brushless DC motor magnetic field is assumed to be independent in each commutation cycle in steady state. Module Tosca for magnetostatic calculations were used. There was calculated electromagnetic torque as a function of angle of rotation of a rotor. Speed of rotor was 6000 rpm.

It was assumed that electric motor is supplied by ideal courses of current. It was assumed that current is nominal I_n=6.5A passing through phases with sequence of switches as shown in fig. 2 to 4. Current courses are presented in function of degrees of rotation. One rotation - 360° mechanical takes 10ms of time. Number of turns of each coil is 54 and diameter of copper wire is 1.1 mm. Rms density of AC current in wire is $J=(I_n/S_{cu})\cdot\sqrt{(2/3)}=(6.5/0.95)\cdot 0.82=5.6$ A/mm^2.

Simulations were conducted in PC computer with Pentium 4 processor 3 GHz and with 1GB RAM. For faster calculations of torque and magnetic field distribution it was assumed linear properties of magnetic materials. Magnetic permeability of soft magnetic composite's stator is 200, rotor steel 500 and permanent magnet with parameters from table 1. Model was divided in 13 thousands surface elements and 130 thousands volume elements. One computer calculation of magnetic field and torque takes about 20 minutes. Electromagnetic torque is presented in fig. 5.

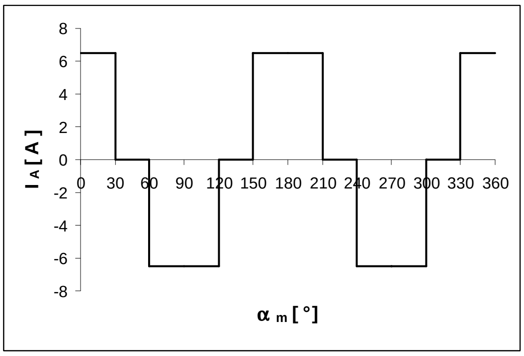

Fig.2. Current in phase A of brushless DC motor as a function of angle of rotation.

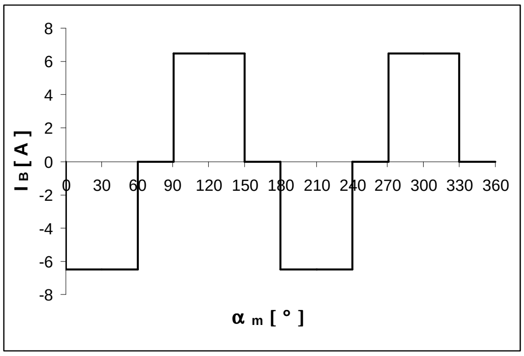

Fig.3. Current in phase B of brushless DC motor as a function of angle of rotation.

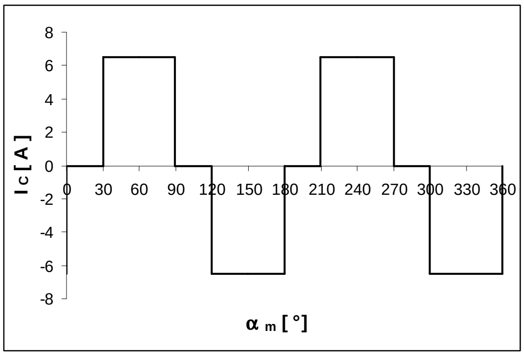

Fig.4. Current in phase C of brushless DC motor as a function of angle of rotation.

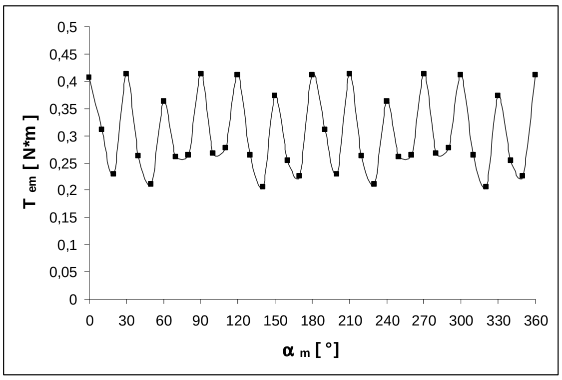

Fig.5. Electromagnetic torque of brushless DC motor as a function of angle of rotation.

Electromagnetic torque was calculated every 10° angle of rotation. Average electromagnetic torque is equal 0.3 N·m calculated from fig. 6. High fluctuations of torque are caused by few numbers of slots and two grooves in a stator.

In fig. 6 there is presented distribution of magnetic flux density in air gap of motor in the middle of a motor's length. Current I_n=6.5A, angle of rotation α_m=0° like was shown in fig. 1.

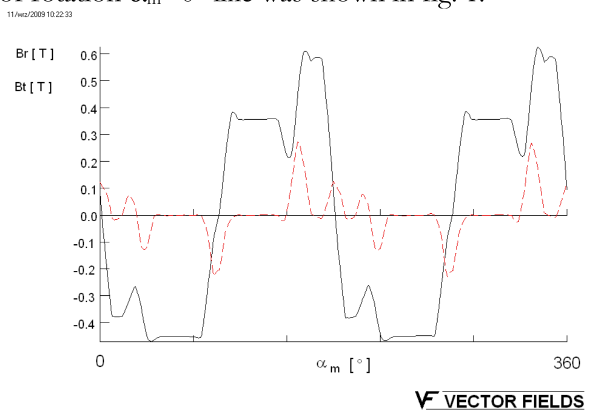

Fig.6. Radial (continuous line) and tangential (dashed line) magnetic flux distribution of brushless DC motor in the air gap.

In fig. 7 there is presented distribution of magnetic flux density in brushless DC motor for current I_n=6.5A for α_m=0°.

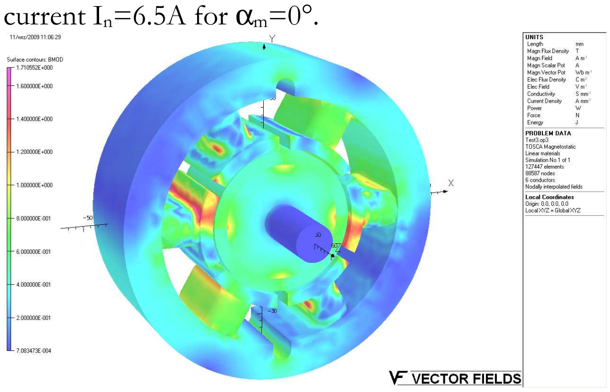

Fig.7. Magnetic flux distribution in brushless DC motor; B_{max}=1.7 T.

In fig. 8 there is presented vectors of magnetic flux density in brushless DC motor for current I_n=6.5A for α_m=0°.

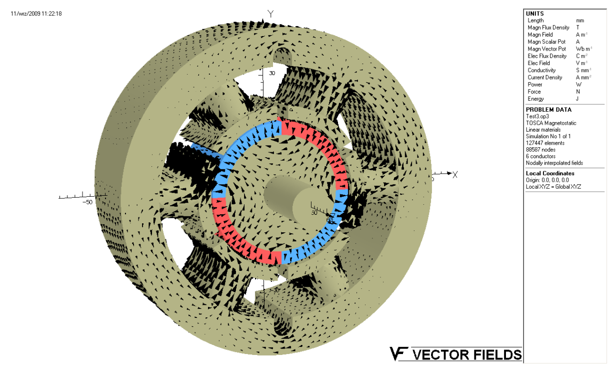

Fig.8. Vectors of magnetic flux distribution in brushless DC motor.

5. Conclusions

Design and analysis of brushless DC motor (BLDC) with iron soft magnetic core and Nd-Fe-B permanent magnets show that it is possible to replace 1 phase AC motor with BLDC motor with the same overall dimensions and operational parameters. Measurements of model BLDC motor will be compared with results of calculations. It will be a base for improvement and optimization of designed motors.

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