Analysis of Single Coil PM-BLDC Motor

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***Abstract*—The aim of the paper is FEM analysis of single coil BLDC motor operated as drive of small piston pump. The paper contains analysis of design, distribution of magnetic field, forces and torque under static and dynamic conditions. Voltages, currents, signals waveforms are also given as the results of analysis. The cogging torque and total torque are discussed in the paper.**

***Index Terms*—ANSYS, BLDC motor, FEM analysis, single coil motor.**

I. Introduction

PERMANENT magnet DC brushless motors are broadly used in small drives. They have many advantages, such as high efficiency, reliability, low production costs and simple control.

Permanent magnet BLDC motors are use in mechatronic, electronic devices like CD-rooms in range of power from tens of miliwatts to hundred watts and range of rotational speed from hundred to several thousand rpm. The motor presented in the paper is dedicated to drive small liquid piston pump. Usually brushless DC motors are made of three or more windings (coils) supplied by electronic full bridge commutator. PM single coil motor is supplied by only single coil, sectioned and distributed along stator circumference, where each subsequent section is wound in opposite direction. Rotor of the motor is made of sectioned permanent magnet. The idea of design of this type of motor and method of its control is known [1]. It is also described in details in the next section. For proposed application it needs detailed analysis of magnetic field, torques and power properties. The main work in this paper is analysis of magnetic field in the motor and its properties at given dimensions and power using ANSYS software (based on FEM method) [2]. Obtained results of FEM analysis are compared with results of measurement. It is necessary to underline that analyzed motor is characterized by its extremely simple power electronic control system of four transistor bridge

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II. Idea of Single Coil BLDC Motor

The rotor of PM-BLDC contains sectioned permanent magnet (Fig. 1) where number of section is equal to number of poles in the stator. Stator is made of even number of coils connected in series and wound, each in opposite direction in respect of neighbor one. The idea of considered rotor is shown in Fig. 1. The most important is direction of coil winding. It is marked in Fig. 2 with arrows. Also direction of coil current is marked by signs (“+” and “-“) and proper color. Control of the stator current is based on the signals of Hall sensors *H* located in the stator (Fig. 1). They detect magnetic field generated by rotor magnets.

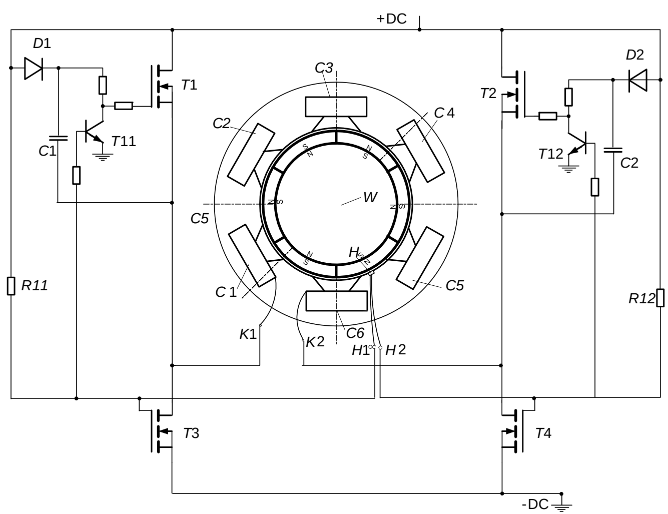

Fig. 1. Schematic diagram of control circuit of PM BLDC single coil motor.

The control circuit of the system with PM-BLDC is depicted in fig. 1. The bridge T1- T4 is switched in pairs (T1-T4) and (T2-T3). Due to the state of the bridge the each half of the stator coils change its polarity. For the state (T1-T4) the coils C1, C3, C5 attract relevant permanent magnet of the rotor while the coils C2, C4, C6 are repulse their counterpart permanent magnets. The direction of the motion is determined with special symmetry of stator. The control is based on Hall sensors that senses the position of the rotor. The rotational speed is proportional to the DC supply voltage that is delivered between +DC and –DC terminals. It is necessary to notice that control circuit having limited number of electronic parts is cheaper than the circuit designed for instance for three phase solution.

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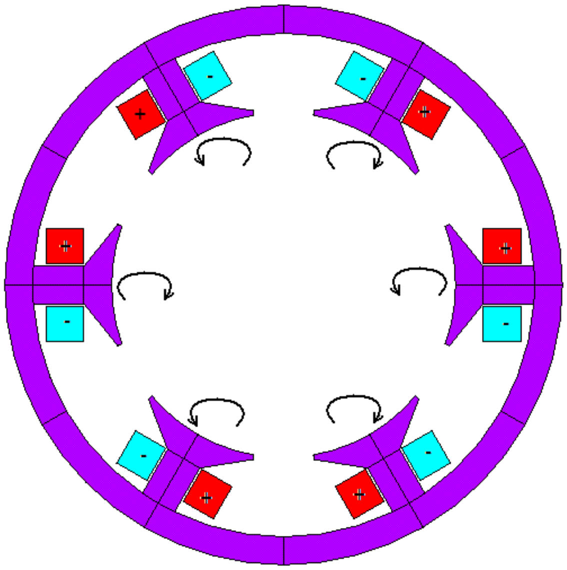

Fig. 2. Stator windings in single coil PM- BLDC motor; opposite marked direction of coil winding and resulted current in coil.

III. Computational Model

Analysis of magnetic field in described motor is calculated using ANSYS software which is based on FEM. Calculations were carried out using 2D planar magnetic model. It is assumed that stator magnetic material operates with linear H-B characteristic. The part of the geometry of 2D ANSYS model with mesh displayed is shown in Fig. 3.

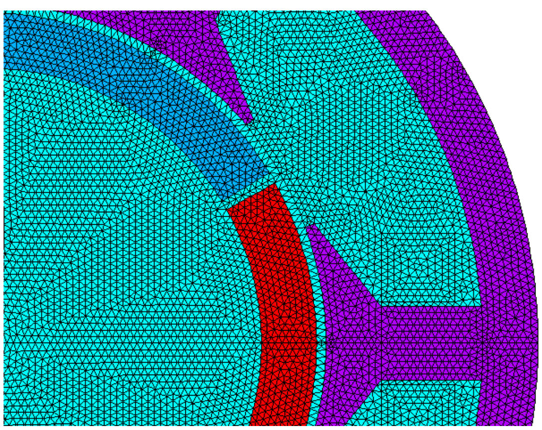

Fig. 3. Stator windings in single coil PM- BLDC motor; opposite marked direction of coil winding and resulted current in coil.

IV. FEM Analysis of Magnetic Field

The analysis of magnetic field allows to optimize design in respect of the motor performance and calculate magnetic forces existing between stator and rotor. Magnetic flux lines in motor with no coil current at 0 deg and 20 deg of rotor position are shown in Fig. 4 and Fig. 5 respectively. One can observe symmetrical flux lines distribution at 0 deg rotor position and closed loops of flux inside of stator pole at 20 deg. Flux distribution influences on cogging torque of motor.

Magnetic flux distribution and current distribution in coils

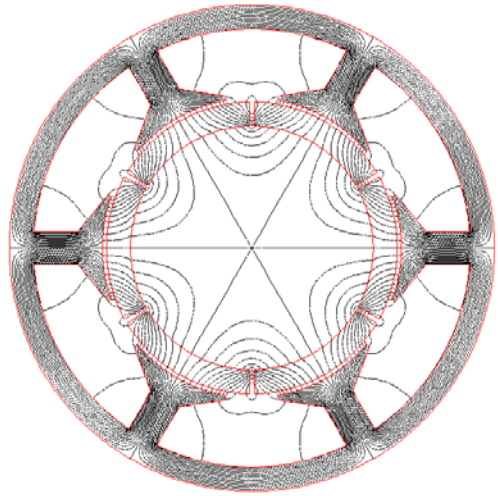

Fig. 4. *2D flux lines in PM BLDC single coil motor (α=0 deg).*

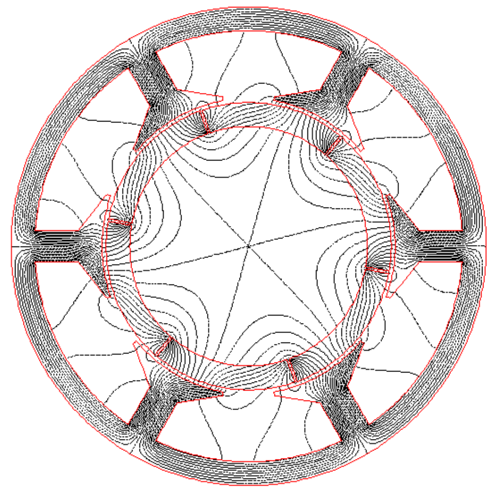

Fig. 5. *2D flux lines in PM BLDC single coil motor (α=0 deg).*

at load current 4 A/turn is shown in Fig. 6. Presented distribution of magnetic field produces no torque at 0 deg position at any current flowing in stator coils.

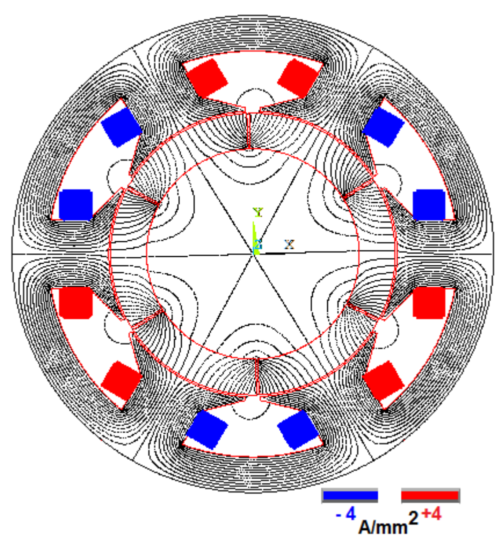

Fig. 6. Magnetic flux density distribution and current distribution at 0 deg of rotor position and 4 A/turn of coil current.

V. FEM Analysis of Torque

Analysis of magnetic field at each position allows to calculate characteristics of torque vs. rotor position at given load current. Both cogging torque and total torque were calculated.

The characteristic of cogging torque vs. rotor position is shown in Fig 7. One can observe high value near 0 deg position and at every 60 deg rotation. Cogging torque hold rotor in proper location in case of no load current. Characteristic of total torque at two different values of load current is shown in Fig. 8 (cogging torque shown for the reference). One can observe no torque at 0 deg and each 60 deg multiple. Because of no load current hold position is the same as for zero torque position at given current. It means that there is no starting torque in the motor.

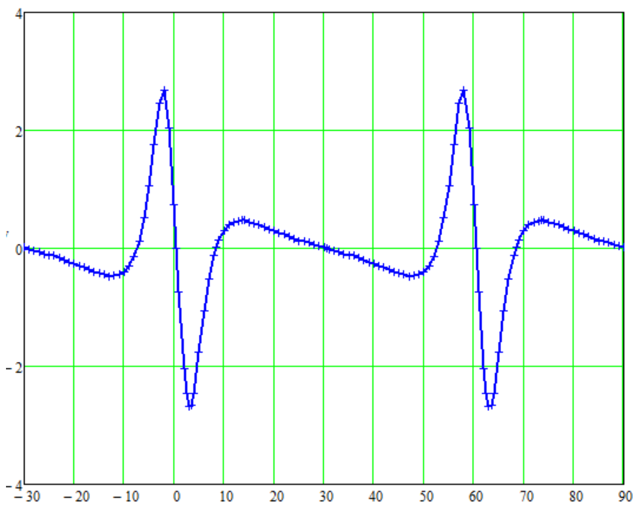

Fig. 7. Cogging torque vs. position of rotor.

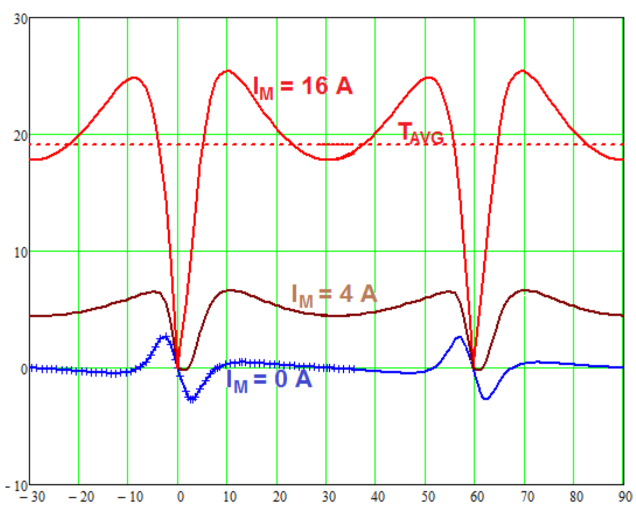

Fig. 8. Total torque vs. position of rotor at different value of load current (16 A/turn, 4 A/turn and 0 A/turn – only cogging torque); T_{AVG} – average value of total torque at 16 A/turn.

VI. The Dent Influence on Starting Torque

In order to obtain non-zero torque at 0 position under non-zero load current modification of stator pole was applied. It consists in inserting of dent for unsymmetrical field distribution. The dent location and magnetic field distribution is shown in Fig. 9. Characteristics of torque vs. rotor position in vicinity of 0 deg is shown in Fig. 10. Two cases are compared, with dent and without dent. One can observe that zero cogging torque is at 1 deg, while torque at load current at this position is non-zero. It means torque produced by current at hold position is non-zero and it allows to start rotation of motor in clockwise direction.

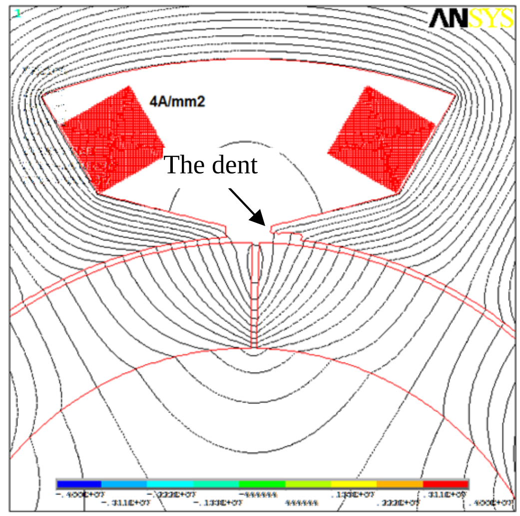

Fig. 9. Magnetic flux density and current density – motor with dent and angle 0 deg and 4 A/turn (4A/mm^2).

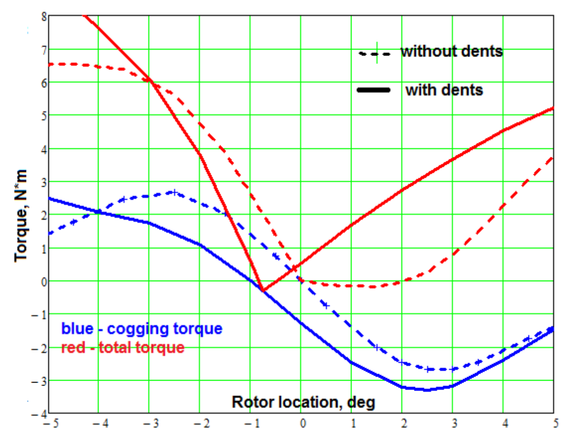

Fig. 10. A torque vs. position of rotor in vicinity of 0 deg position, comparison of motor poles with dents and without dents at 4 A/turn.

VII. Conclusions

- Permanent magnet brushless single coil DC motor described in [1] is analyzed.
- Features of the analyzed single coil DC motor are slightly different comparing with standard three phase motor.
- Future works will be concentrated on analysis of circuit model based on FEM.

References

[1] Gerfast S. R.: “Single coil, direct current permanent magnet brushless motor with voltage boost”, US Patent 6940238, September 2005

[2] ANSYS Software Manual