Torque Improvement for an Exterior Rotor Permanent Magnet Brushless DC Motor

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Abstract: A method of simulation and modeling outer exterior permanent magnet brushless DC motor under dynamic conditions using finite element method by FEMM 4.2 software package is presented. In the proposed simulation, the torque developed at various positions of the rotor, under a complete cycle of excitation of the stator is analyzed. Computer simulations and conventional results show the usefulness of the proposed method.
Keywords: Exterior rotor brushless Permanent Magnet DC Motor (ERPMBLDCM), Finite Element Method (FEM), Flux, Magnetic Vector Potential and torque.

1. INTRODUCTION

The impressive improvement in power electronic switching devices, integrated circuits, developments and refinements in permanent-magnetic materials, and manufacturing technology have led to the development of brushless permanent- magnet motors that offer significant improvements in power density, efficiency, and noise reduction. Brushless permanent-magnet motors are especially demanded in clean and explosive environments such as aeronautics, robotics, food and chemical industries, electric vehicles, medical instruments, and computer peripherals [4],[5] and[6].PM D.C. Brushless Motors use direct feedback of the rotor angular position so that the input armature current can be switched, among the motor phases, in exact synchronism with the rotor motion. This concept is known as self-controlled synchronization, or electronic commutation. The electronic inverter and position sensors arc equivalent to the mechanical commutator in D.C. motors [6].

There are several reasons for the overwhelming prevalence of motors having inner rotors [5]. These reasons include the ease of heat removal, because the windings are on the outside, and the containment of the rotating element. In some applications, these attributes are not as important as the benefits gained from having an outer rotor and inner stator. Motors having this construction are sometimes called inside-out motors. Outer rotor motors appear most commonly as spindle motors for hard disk drives and as the drive motor for ventilation fans, such as those used to cool CPUs and computer cases. In these applications, the motor becomes an integrated part of a larger structure. Although individual magnets can be used in outer rotor motors, it is common to use a single bonded magnet ring inside a rotor. Since the stator teeth point outward, this motor is relatively easy to wind. For a given outer radius, an outer rotor motor has a much larger air gap radius than that of an inner rotor motor. As a result, higher torque is achievable, provided the ohmic losses the stator windings can be dissipated [8] and [10].

The finite element method (FEM) has proved to be particularly flexible, reliable and effective in the analysis and synthesis of power-frequency electromagnetic and electromechanical devices .Even in the hands of non specialists, modern FEM packages are user friendly and allow for calculating the electromagnetic field distribution and integral parameters without detailed knowledge of applied mathematics. The FEM can analyze PM circuits of any shape and material. There is no need to calculate reluctances, leakage factors or the operating point on the recoil line. The PM demagnetization curve is input into the finite element program which can calculate the variation of the magnetic flux density throughout the PM system. An important advantage of finite element analysis over the analytical approach to PM motors is the inherent ability to calculate accurately armature reaction effects, inductances and the electromagnetic torque variation with rotor position (cogging torque) [2]-[3], [8] and [13].

In electrical machine problems four methods of calculating forces or torques are used: the Maxwell stress tensor, the co-energy method, the Lorentz force equation, and the rate of change of field energy method. The most appropriate method is usually problem- dependent, although the most frequently used is the Maxwell stress tensor method [12].

FEMM package is an open source, simple, accurate, and low computational cost freeware product, popular in science and engineering. Several applications in areas such as Electromagnetic, Materials Science, Industry, Medicine, Experimental and Particle Physics, Robotics, Astronomy, and Space Engineering can be found. The software is reasonably fast and accurate, user friendly, and freely distributed. The last seems to be its main advantage concerning its educational value. Its capability to meet as a complementary tool the needs of teaching electromagnetic in higher education will be explored and evaluated [1].

In the proposed model FEMM4.2 software package has been used to investigate the excitation currents to the different phases of stator windings and corresponding torque developed to enhance the torque produced by ERPMBLDC Motors.

2. MODELING OF ERPMBLDC MOTOR BY FEMM4.2

Finite element method a magnetic (FEMM4.2) is the software package has been used to model the ERPMBLDC motor. FEMM 4.2 is a suite of programs for solving low frequency electromagnetic problems on two-dimensional planar domains. The program currently addresses linear/nonlinear magneto static problems, linear/nonlinear time harmonic magnetic problems, linear electrostatic problems, and steady-state heat flow problems. FEMM4.2 is divided into three parts. Interactive shell (femm.exe). This program is a Multiple Document Interface pre-processor and a post-processor for the various types of problems solved by FEMM4.2. It contains a CAD like interface for laying out the geometry of the problem to be solved and for defining material properties and boundary conditions. AutoCAD DXF files can be imported to facilitate the analysis of existing geometries [1]. Field solutions can be displayed in the form of contour and density plots. The program also allows the user to inspect the field at arbitrary points, as well as evaluate a number of different integrals and plot various quantities of interest along user-defined contours triangle.exe. Triangle breaks down the solution region into a large number of triangles, a vital part of the finite element process. Each solver takes a set of data files that describe problem and solves the relevant partial differential equations to obtain values for the desired field throughout the solution domain.

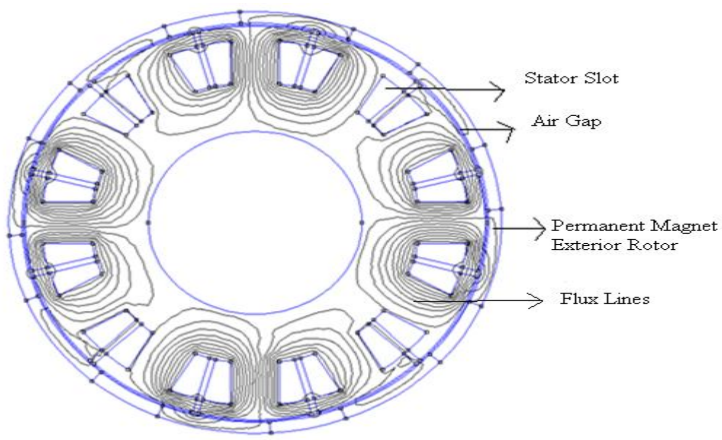

Fig 1. Flux plot

The permanent magnet of outer rotor material property is chosen as ALNICO 8 and stator with silicon core iron. Stator windings are excited by three phases namely A,B and C. The motor has been modeled with 5894 nodes and11419 elements by 2D planar..Flux lines established and flux density distribution for the given excitation in three phases are shown in Fig.1 and 2 respectively.

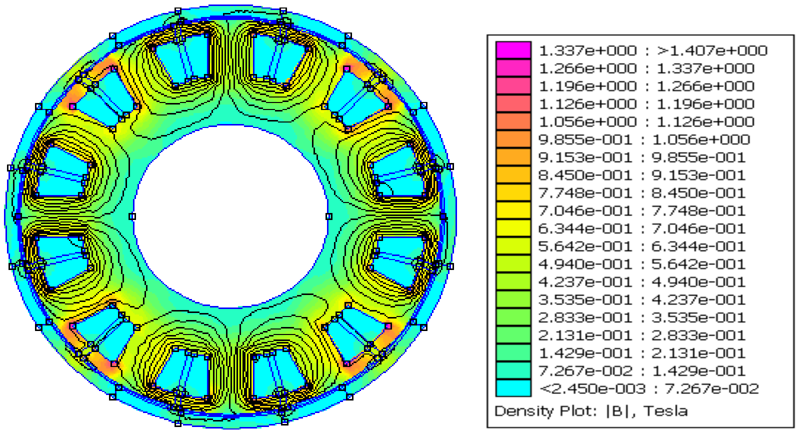

Fig 2. Magnetic flux density distribution

3. SIMULATION RESULTS

The three phase stator windings are excited by phase currents A, B and C by varying the phase angles from 0^0-360^0 with interval of 5 i.e. totally 73 iterations for each rotor position. The corresponding torque values are investigated. This procedure is repeated for rotor angles from 0^0- 90^0 with an increment of 2.5^0. Torque for various phase angles from 0^0-360^0 with interval of 10 (for simplicity) for rotor at starting position at 00^0 and 87.5^0 has been depicted. Fig 3. shows Phase angle Vs torque for three rotor position angles that is for 00^0, 2.5^0 and 5^0. Maximum torques and corresponding phase angles are noted for each rotor position. They are 0.01511N-M and 270.246^0 for rotor angle 00^0, 0.07868 N-M and 300.273^0 for rotor angle 2.5^0 and 0.03765 N-M and 310.282^0 for rotor angle 5^0 respectively.

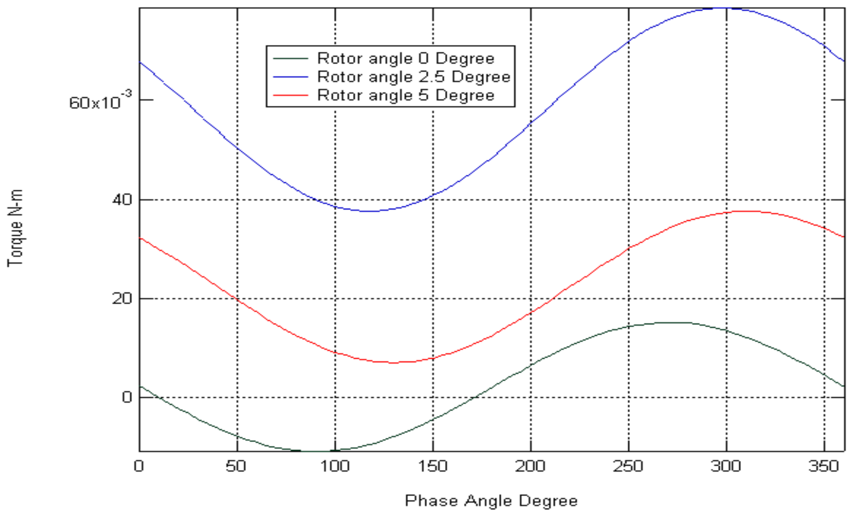

Fig 3. Torque for various rotor position angles (00^0 to 5^0)

For each rotor position peak torque value is determined and in total 36 rotor positions are studied for one quadrant. As the motor model is being axisymmetry investigations are carried out for one quadrant. A plot between peak torque values and rotor angles has been obtained as in Fig 4. It is observed from the plot the torque developed by the ERPMBLDC motor can be improved to approach the ideal torque by designing the switching circuit to the motor drive to supply the phase current to develop the maximum torque for particular rotor positions. The average torque developed will be the maximum for the particular machine and hence the output power. The efficiency of the motor will be maximum at any load.

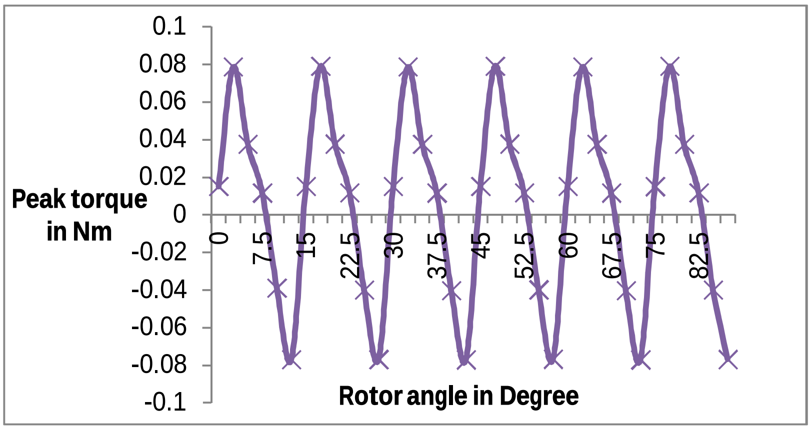

Fig 4. Rotor angle Vs peak torque

4. CONVENTIONAL BACK EMF METHOD FOR ERPMBLDC MOTOR

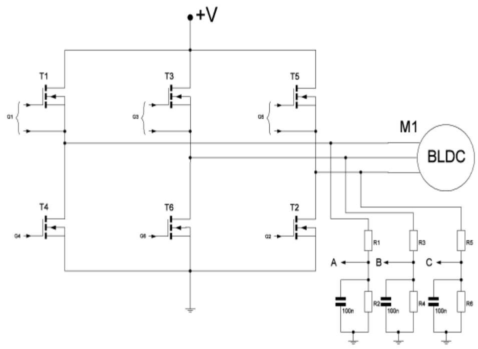

Fig5. Power Circuit for BLDC motor

A Power Circuit for BLDC motor by a three-phase inverter with, is called, six-step commutation shown in figure5. The conducting interval for each phase is 120^0 by electrical angle. The commutation phase sequence is like Q_1Q_2- Q_1Q_3- Q_2Q_3- Q_2Q_1- Q_3Q_1- Q_3Q_2. Each conducting stage is called one step. Therefore, only two phases conduct current at any time, leaving the third phase floating. In order to produce maximum torque, the inverter should be commutated every 60^0 so that current is in phase with the back EMF. The commutation timing is determined by the rotor position, which can be detected by Hall sensors or estimated from motor parameters, i.e., the back EMF on the floating coil of the motor if it is sensorless system. In brushless dc motor, only two out of three phases are excited at one time, leaving the third winding floating. The back EMF voltage in the floating winding can be measured to establish a switching sequence for commutation of power devices in the three-phase inverter. Fig.6 shown Output of power circuit ($V_{R\ phase\text{-}phase}$) of conventional method.

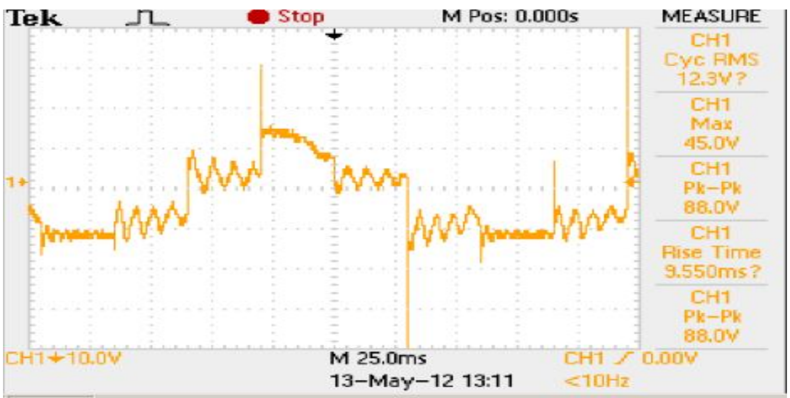

Fig.6 Output of power circuit ($V_{R\ phase\text{-}phase}$) of conventional method

A few other schemes for sensorless BLDC motor control were also reported in the literature. The back EMF integration approach has the advantage of reduced switching noise sensitivity and automatically adjustment of the inverter switching instants to changes in the rotor speed [15]. The back EMF integration still has accuracy problems at low speeds. The rotor position can be determined based on the stator third harmonic voltage component [16]. The main disadvantage is the relatively low value of the third harmonic voltage at low speed. In [17], the rotor position information is determined based on the conducting state of free-wheeling diodes in the unexcited phase. The sensing circuit is relatively complicated and low speed operation is still a problem. Table 1. For conventional method Vs Peak torque for simulation methods.

Table 1. Conventional Vs Peak torque for simulation

Rotor angle	Conventional Torque (N-M)	Peak torque for simulation Torque (N-M)
0	0.01336	0.01511
5	0.0333	0.03765
15	0.0133	0.01505
20	0.0334	0.03771
30	0.0133	0.01509
37.5	0.0102	0.01159
47.5	0.0699	0.07911
60	0.0133	0.01512
65	0.0333	0.03766
80	0.0333	0.03766
82.5	0.0104	0.01178

6. CONCLUSION

Computational procedure for the finite element method and its application to solve magnetic field problems in ERPMBLDC Motor is presented. In a two dimensional magnetic field model of ERPMBLDC Motor the magnetic field distribution and peak torque in a cross section of the Motor by proposed technique have been computed. Results from simulation study and verified over the conventional method. Torque developed by conventional method is less compare to those by peak torque method since in conventional method stator windings are excited by respective phases to move rotor in forward direction according to rotor position. In peak torque method stator windings are excited not only by respective phases but also at phase angles corresponding to peak torque to yield maximum torque at any rotor position.

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