Design and Analysis of PMBLDC Motor

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Abstract— Interest has grown in the use of brushless permanent magnet motors due their high efficiency and low maintenance cost compared to conventional motors. The use of permanent magnet in electrical machines in place of electromagnetic excitation results in many advantages such as no excitation losses, improved efficiency, fast dynamic performance, and high power density. Design of Brushless Permanent Magnet motors can be intensive due to the requirement of many design constraints. Many optimization routines exist, but require knowledge of design constraints from an existing design in order to function. This project present a Radial Flux Permanent Magnet Brushless DC motor design. This Radial Flux Permanent Magnet Brushless DC motor designed meets user input specifications. In this project, the basic design equations are derived and developed the CAD program. The Developed CAD program calculates and estimates the performance.

Key words: PMBLDC Motor, CAD Program, DC Motor Design

I. INTRODUCTION

Permanent Magnet machines are increasingly becoming dominant machines with the cost competitiveness of high energy permanent magnets. These machines offer many unique features. They are usually more efficient because of the fact that field excise tat ion losses are eliminated resulting in significant rotor loss reduction. Thus, the motor efficiency is greatly improved and higher power density is achieved. Moreover, PM motors have small magnetic thickness which results in small magnetic dimensions. They can be designed to have a higher power-to-weight ratio resulting in less core material. The noise and vibration levels are less than the conventional machines. Also, the direction of the main air gap flux can be varied and many discrete topologies can be derived. They are used in naval and domestic applications like pumps, fans, valve control, electrical vehicles, centrifuges, machine tools. There are many topologies of the machine and the machine topology is determined by magnetic or non-magnetic stator.

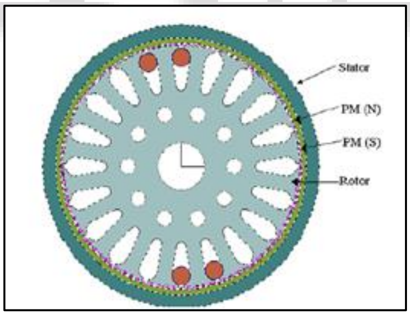
All brushless PM motors are constructed with electrical windings on the stator and permanent magnets on the rotor. This construction is one of the primary reasons for the increasing popularity of brushless PM motors. Because the windings remain stationary, no potentially troublesome moving electrical contacts, i.e., brushes are required. In addition, stationary windings are easier to keep cool. Brushless DC Motors are one of the motor types rapidly gaining popularity.

II. PERMANENT MAGNET BRUSHLESS DC MOTORS DESIGN POSSIBILITY

1) Radial flux Permanent magnet brushless DC motors
2) Axial flux permanent magnet brushless DC motors

A. *Features of Radial Flux Permanent Magnet:*

Conventional Radial Flux Permanent Magnet machines is used extensively from decades. Many papers exist in the literature concerning the radial flux permanent magnet machine, the most common type of permanent magnet machine used in industry. These machines are well known to have higher torque capability than the more conventional motor. The efficiency is also higher than the conventional motor due to the lack of rotor windings. It has higher power density and higher torque per ampere ratio. However, an important manufacturing disadvantage of the radial fluxpermanent magnet brushless DC motor is that magnet maintenance must be care- fully implemented so that the rotor does not fly apart. The non-slotted version of the conventional radial flux permanent magnet machine has also been analyzed in the literature. The two major differences between the slotted and non-slotted versions of the radial flux permanent magnet machine are the existence of slots and the type of poly-phase winding. The stator structure is non-slotted and consists of a stack of laminated steel. Back-to-back connected poly-phase windings are wrapped around the stator in a toroidal fashion and termed air gap windings since the windings are not placed into slots. The places in between the windings are filled with epoxy resin to increase robustness and provide better conductor heat transfer. The rotor structure is formed by surface mounted NdFeB magnets, rotor core and shaft.



B. *Magnet Material Properties:*

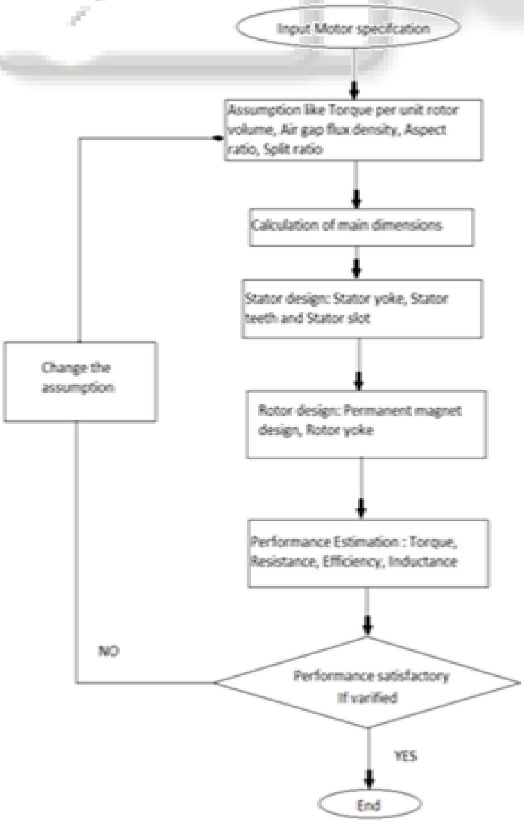
Material	Composition (wt %)	Remanence B_r [tesla (gauss)]	Coercivity H_c [amp-turn/m (Oe)]	$(BH)_{max}$ [kJ/m^3 (MGOe)]	Curie Temperature T_c [°C (°F)]	Resistivity ρ (Ω-m)
Tungsten steel	92.8 Fe, 6 W, 0.5 Cr, 0.7 C	0.95 (9500)	5900 (74)	2.6 (0.33)	760 (1400)	3.0×10^{-7}
Cunife	20 Fe, 20 Ni, 60 Cu	0.54 (5400)	44,000 (550)	12 (1.5)	410 (770)	1.8×10^{-7}
Sintered alnico 8	34 Fe, 7 Al, 15 Ni, 35 Co, 4 Cu, 5 Ti	0.76 (7600)	125,000 (1550)	36 (4.5)	860 (1580)	—
Sintered ferrite 3	$BaO–6Fe_2O_3$	0.32 (3200)	240,000 (3000)	20 (2.5)	450 (840)	$\sim 10^4$
Cobalt rare earth 1	$SmCo_5$	0.92 (9200)	720,000 (9,000)	170 (21)	725 (1340)	5.0×10^{-7}
Sintered neodymium-iron-boron	$Nd_2Fe_{14}B$	1.16 (11,600)	848,000 (10,600)	255 (32)	310 (590)	1.6×10^{-6}

III. COMPUTER AIDED DESIGN FOR PMBDC MOTOR

Sr. No.	Temprature 0 C	Relativel Permia-bility	Corecivity A/m
1	-40	1.07148	-835517
2	20	1.06015	-813242
3	60	1.08184	-775117
4	100	1.06657	-742988
5	140	1.05723	-707826
6	180	1.60262	-651274

Here the Computer Aided Design of the Radial flux permanent magnet motor is carried out. Flow chart of design process is also shown in fig4.1. Selection of motor among all the topology was carried out. This flow chart has one decision making loop. The loop correction for the air gap flux density, torque per unit volume, aspect ratio, split ratio is to be carried out. Decision making loops will be active till the error between assumed quantities and actual quantities is within acceptable limit. Electrical and Mechanical performance of motor depends on geometry and selection of materials. With the help of CAD programming, the different parameters of motor like length of motor, stator outer diameter, rotor outer diameter, torque, number of stator slot per pole per phase, phase voltage, phase current, conductor area, number of turns per slot, number of conductor, stator yoke width, rotor yoke width, tooth body width, stator back iron radius, stator inner radius, rotor inner radius, slot bottom width, total slot depth, shoe depth, conductor slot depth, width of teeth, conductor cross sectional area, slot width beyond shoe, wire guage, efficiency, phase resistance, phase inductance is found out.

A. *Selection of Bg:*



Air gap flux density should be as high as possible, it is needed for the desired torque production. For the permanent magnet motor flux is produced by the magnet. Length of the magnet highly affects flux density at airgap. Also higher length of magnet cause to increase overall cost of the motor and that is not permissible. Lower length of magnet cause to decreases mechanical strength of the magnet. Here Bg varies between 0.45 to 0.9. If Bg is greater than 0.7 than change in length of magnet is much higher. Here Bg value selected for the 200 W motor is 0.6 T and and the for the 2200 W motor is 0.8 T.

B. *Selection of Materials:*

1) *Permanent Magnet Material:*

Out of various types of permanent magnet materials commercially available as on day, Neodymium-Iron Boron (NdFeB) is having highest energy product and also the highest residual flux density. The high remanence and coercivity of NdFeB material enables it appreciable reduction in motor frame size for the same output compared to other type of permanent magnet materials. As it is planned to have a compact, efficient and high power density motor for the elective two-wheeler, it is decided to use NdFeB permanent magnet, the magnetizing characteristics of NdFeB magnet is a straight line. The magnetic properties of which are given below. Residual induction Br at 20^0C is 1.08 Tesla. Energy Product at 20^0C is 220.3 kJ/m^3

C. *Magnetic Permeability:*

1) *Magnetic Demagnetization:*

Sr. No.	Temperature^{0}C	Demagnetization T
1	-40	0
2	20	0
3	60	0
4	100	0
5	140	0.208
6	180	0.4447

2) *Electric Resistivity:*

Sr. No.	Temperature^{0}C	Resistivity $\Omega\times$m
1	20	1.5×10^{-6}

3) *Thermal Conductivity:*

Sr. No.	Temperature^{0}C	Conductivity (W/m^{0}C)
1	20	9

4) *Thermal Specific Heat Capacity:*

Sr. No.	Temperature^{0}C	Specifi Heat Capacity (J/kg^{0}C)
1	20	460

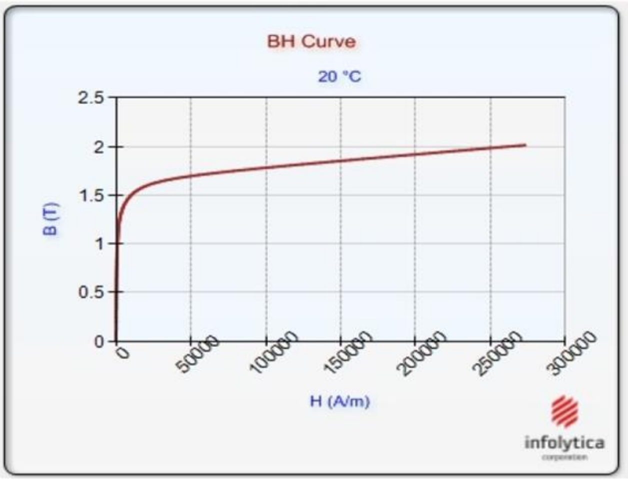
5) *Mass Density:*

Sr. No.	Temperature^{0}C	Mass Densityg/m^3
1	20	7500

D. *Rotor Core Material:*

Here Rotor core material is 416 grade stainless steel which is ferro magnetic so the producing field is strong. This is done as the rotor core always carry a unidirectional flux produced by the permanent magnet and also as the effect of armature reaction is negligible owing to a large Airgap (the PM also act as an Airgap due to μr =1). Laminations are not required for the rotor core. Therefore a solid rotor core is con- sidered, which will improve fabrication feasibility and mechanical strength.

Material: S416 Grade stainless steel



1) *Electric Permittivity:*

Sr. No.	Temperature^{0}C	Relative Permeability
1	20	1

Electric Conductivity

Sr. No.	Temperature ^{0}C	Conductivity S/m	Conductivity %IACS
1	20	0	0

Electric Permittivity

Sr. No.	Temperature ^{0}C	Relative Permeability
1	20	1

Thermal Conductivity

Sr. No.	Temperature ^{0}C	Conductivity (W/m^{0}C)
1	20	49.8

Thermal Specific Heat capacity

Sr. No.	Temperature ^{0}C	Specific Heat Capacity (J/kg^{0}C)
1	20	448

Mass Density

Sr. No.	Temperature ^{0}C	Mass Densitykg/m^3
1	20	7600

2) *Magnetic Permeability:*

Sr. No.	Temperature0C	Relative Permeability	Coercivity A/m
1	20	1	0

Electric Resistivity

Sr. No.	Temperatures ^{0}C	Resistivity $\Omega \times$m
1	-100	9.1724×10^{-9}
2	20	1.7241×10^{-8}
3	1000	8.3138×10^{-8}

Electric Permittivity

Sr. No.	Temperatures ^{0}C	Relative Permeability
1	20	1

Thermal Conductivity

Sr. No.	Temperatures ^{0}C	Conductivity (W/m^{0}C)
1	20	387.7

Thermal Specific Heat capacity

Sr. No.	Temperature ^{0}C	Specific Heat Capacity (J/kg^{0}C)
1	20	393.5

Mass Density

Sr. No.	Temperatures ^{0}C	Mass DensityKg/m^3
1	20	8940

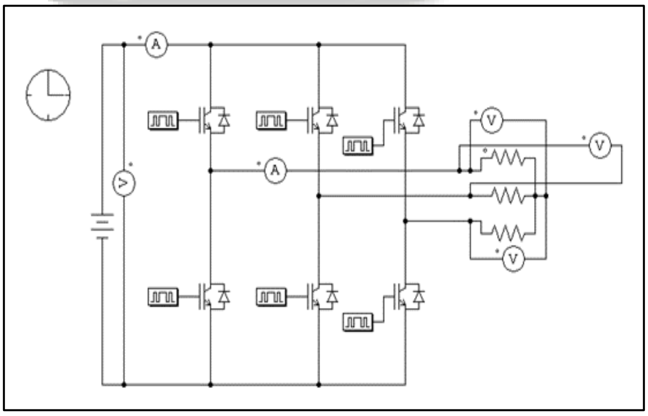
3) *CAD Output with Magnet for 746W, 48V, 2000rpm motor:*

1.	Output Power (Po)	746 W
2.	Supply Voltage(V)	48 V
3.	Speed(rpm)	2000 rpm
4.	Torque	3.5619 N-m
5.	No. of stator slot(Ns)	24
6.	No.of phase(Nph)	3
7.	No of coil excited Simultaneously(Nc)	2
8.	No of Poles(P)	4
9.	No.of stator per pole per phase(Nspp)	2
10.	Winding factor(Kw)	0.9
11.	Specific magnetic loading(Bg)	0.8000 T
12.	Stator outer diameter(Dso)	0.1261m
13.	Rotor outer diameter(Dro)	0.0710m
14.	Length of motor(L)	0.0500m
15.	Length of Air Gap(lg)	5.0000 ê-04m
16.	Length of magnet(Lm)	0.0490m
17.	Stacking factor(Kst)	0.9500
18.	Phase voltage(Eph)	24

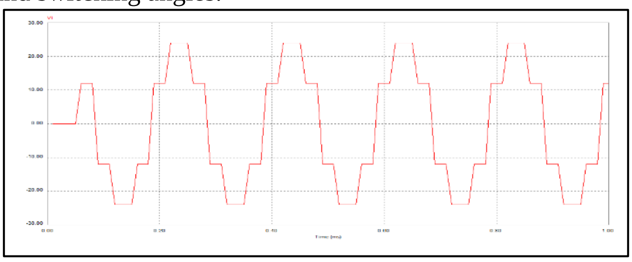
19.	Phase Current(Iph)	16.3596A
20.	No. of Conductor per phase(Zph)	51.1428
21.	No. of Turns per slot in single layer	6
22.	No. of Turns per slot in double layer	12
23.	Stator yoke width(Wsy)	0.0162m
24.	Rotor yoke width or core thickness(Wry)	0.0204m
25.	Tooth body width(Wtb)	0.0042m
26.	Stator back iron radius(Rsb)	0.0469m
27.	Stator inner radius(Rsi)	0.0360m
28.	Rotor inner radius(Rri)	0.013m
29.	Slot bottom width(Wsb)	0.0080m
30.	Total slot depth(Ds)	0.0109m
31.	Shoe depth(D1)	0.0016m
32.	Shoe depth(D2)	0.0016m
33.	Conductor slot depth(D3)	0.0077m
34.	Slot opening(Ws)	0.0019m
35.	Width of teeth(Wt)	0.0074m
36.	Conductor cross sectional area(As)	5.4354 ê-05m^2
37.	Slot width beyond shoe(Wsi)	0.0060m
38.	Diameter of Wire	6
39.	Torque per unit volume(Ktrv)	18KN/m^2
40.	Efficiency (derived)	0.95%

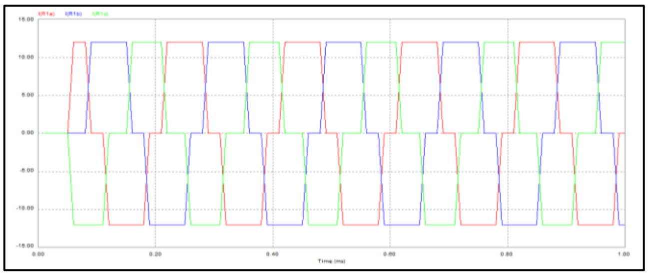
IV. Simulation and Result

A. Six Step Commutation in PSIM:



Waveforms of Line Voltage, Phase Voltage and Phase Currents are obtained by setting proper switching frequency and switching angles.





V. Conclusion

- PMBLDC motor has certain advantages of high torque/current ratio, high
- Efficiency, fast dynamic performance compared to conventional motor.
- With a help of MagNet Design Analysis is carried out for 746W, 2000rpm, 48V PMBLDC Motor. Formulas of different parameters are implemented and dimensions are used in MagNet.
- Magnet Software is also used to design PMBLDC Motor Initially.

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