Design of Permanent Magnet Motor for Automotive Applications

Major Project Report

Submitted in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING

(Power Electronics, Machines and Drives)

By

Rashmi Meena

(18MEEP15)

DEPARTMENT OF ELECTRICAL ENGINEERING

INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

AHMEDABAD-382481

MAY 2020

Certificate

This is to certify that the Project Report entitled ”Design of Permanent Magnet Motor for Automotive Applications” submitted by Miss. Rashmi Meena (18MEEP15), towards the partial fulfillment of the requirements for the award of degree of Master of Technology in Power Electronics, Machines and Drives of University is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

Prof. Amit N. Patel
Project Guide
Assistant Professor
Department of Electrical Engineering
Institute of Technology
Nirma University
Ahmedabad

Head Of Department
Department of Electrical Engineering
Institute of Technology
Nirma University
Ahmedabad

Additional Director
School of Engineering
Institute of Technology
Nirma University
Ahmedabad

Undertaking For Originality Of The Work

I, Rashmi Meena, Roll. No. 18MEEP15, give undertaking that the Major Project entitled *"Design of Permanent Magnet Motor for Automotive Applications"* submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology with specialization in Power Electronics, Machines and Drives of School of Engineering, Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere, it will result in severe disciplinary action.

Signature of Student
Date:
Place: Ahmedabad

Endorsed By

Prof. Amit. N. Patel
Project Guide
Assistant Professor
Department of Electrical Engineering
Institute of Technology
Nirma University
Ahmedabad

ACKNOWLEDGEMENT

With immense pleasure, I express my deep and sincere gratitude, regards and thanks to my guide and supervisor **Prof. Amit N. Patel**, Assistant Professor, Department of Electrical Engineering, Institute of Technology, Nirma University, Ahmedabad whose keen interest and excellent knowledge helped me to carry out the present project work and for his constant encouragement and guidance during the working period without which it would be very strenuous for me to get a proper bias for work required to be carried out for outmatching major project work.

I am thankful to **Dr. S. C. Vora**, Professor, Head of Department of Electrical Engineering,Institute of Technology, Nirma University, Ahmedabad for his kind help and encouragement for my project work and **Dr. R. N. Patel**, Additional Director, Institute of Technology, Nirma University, Ahmedabad for providing all kind of required resources during the course of study. Last but not the least, I would like to specially thank **Prof. Tejas H. Panchal** for his continues encouragement and motivation throughout the phase of project.

- Rashmi Meena
18MEEP15

Abstract

The Permanent Magnet (PM) Motor technologies has become a more viable option as it offers a high torque density and high efficiency. Presently, permanent magnet motors are widely used in automotive applications. The automotive industry is the largest user of permanent magnet motors. Permanent magnet motor design is proposed in the given thesis which is suitable because of its superior performance in the field of automotive application. The proposed PM motor was designed and simulated using motor solve software. Motor performance parameters were validated using results obtained from simulation software. The proposed motor design not only enhanced the performance of the PM motor but also reduced the cost and size. The simulation work on all parametric analysis of PM motor,even a comparative analysis was also performed between the initially designed motor and proposed design motor.

Abbreviations

DC	Direct Current
PM	Permanent Magnet
BLDC	Brushless Direct Current
PMDC	Permanent Magnet Direct Current Motor
IPM	Interior Permanent Magnet
FEA	Finite Element Method
PMSM	Permanent Magnet Synchronous Motor

Contents

ACKNOWLEDGEMENT

Abstract

Abbreviations

List of Figures

List of Tables

List of Figures

List of Tables

Chapter 1

Introduction to Permanent Magnet Motor

1.1 General

Permanent Magnet technology offering substantial estimates the high defined the torque and small losses. This makes them appropriate for use in the automotive industry. Magnet accessibility is questionable, due to significant high costs. The transportation system for the future must fuse electric traction technology for a wide area.Therefore, a rare earth-free machine or reduction of rare earth PM machines happens majorly.

The propulsion system uses various motors, such as low-cost PM, induction reticence switched and synchronous reticence motors. For automotive applications the various types of low-cost PM or rare-earth free motors. For automotive applications the advantages and disadvantages for electric motors are added.

1.2 Classification of Electric Motors

1.2.1 Permanent Magnet DC Motor

The permanent DC motor magnet acts on DC motor configuration. As with a permanent DC magnet motor, the armature is positioned within the permanent magnet's magnetic field, the armature rotates against the generated power.

$$F = BIL \tag{1.1}$$

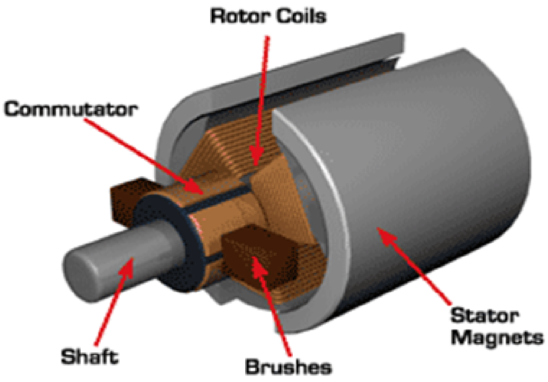


Figure 1.1: PMDC Motor

Constructional Feature

Permanent DC magnet motor, indicate the field poles are essentially made of a permanent magnet, and the stator and rotor are two steel cylinders. The magnets are mounted onto the inner periphery of the rotor. This extra material acts as an extra air gap between the rotor surface and the magnets to hold the magnet as a binding agent on the outer edge of the ring, this additional material acts as an extra air gap between the rotor's outer surface and the magnets The cylindrical stator made of M19 material also accommodates a low reluctance magnetic flux return path.

The design of the rotor is similar to conventional DC motor. It also comprises the core, windings and commutator.

1.2.2 Permanent Magnet Brushless D C Motor

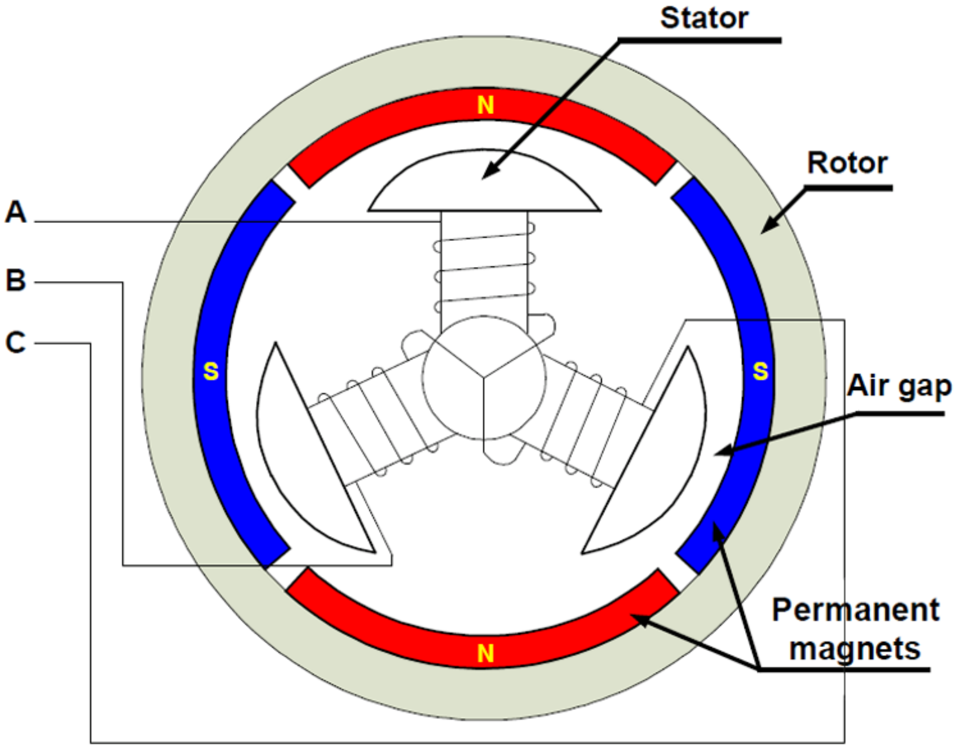


Figure 1.2: BLDC Motor

- A BLDC motor is a type of permanent DC motor with magnet. Like PMDC motor, it has twisted stator windings, and a permanent magnet rotor.
- Here are Hall effect sensors for smooth speed control and efficient operation in BLDC.
- Hall effect sensor located on the side of a stator or rotor. This transducer assists in deciding rotor position.
- After rotor location determinations we can adjust field winding excitation.
- This change in excitation allows the rotor to the rotor or, in other words, the rotor should obey their respective direction of pole.

1.2.3 Comparison Between PMDC Motor and PMBLDC Motor

Compared to the permanent dc(PMDC) magnet motor,permanent magnet brushless dc(PMBLDC)MOTOR system types demonstrate clear advantages in many respects:

- PMBLDC uses hall location sensor based electronic commutation and PMDC uses brushed switching.
- Due to the absence of the brushes PMBLDC needs less maintenance while PMDC needs regular maintenance.
- PMBLDC has longer operating life than PMDC.
- PMBLDC's efficiency is higher. Thus there is no decrease in voltage between brushes.
- PMBLDC results in superior thermal properties resulting in reduced scale. The heat dissipation is better as BLDC has the windings of the stator which are connected to the panel. The power / frame output is low, or moderate.
- PMBLDC's speed range is higher. Thus, brushes or commutators do not place any mechanical limitations. Speed frequency is smaller.

For this work the Permanent Magnet Brushless DC Motor was chosen.Through designing a motor the output parameters can be improved. The motor size will be made more compact, and the motor cost will be reduced.

1.2.4 Features of Permanent Magnet Brushless DC Motor

Advantages

- Better speed vs.the torque features
- Faster and more dynamic response
- Higher efficiency
- Operating life is long
- Noise-free operation
- Speeds higher

Disadvantages

- Electronic Controller Required
- Higher costs.
- Needs circuit-drive power
- Extra sensors required

Applications

- Fast Drives computers and DVD / CD players
- Hybrid buses, electric cars and e-bikes
- Industrial robots, CNC machine tools and core systems driven by belt
- Washers, dryers, and compressors
- Pumps and blowers for fans

1.3 Constructional Aspects

Brushless motors such as permanent magnets and switched reluctance motors rely on electronic drive systems that produce rotating magnetic fields to pull the rotors around them. The discovery of new magnetic materials, such as Neodymium alloys with high magnetic concentration and high coercion capable of mounting and maintaining powerful magnetic fields, has made a number of innovative brushless motor designs possible by removing one set of traditional motor windings;The pump, or the stator. However, the implementation of many of these brushless designs was only made possible through the availability of low-cost high-power switching semiconductors that allowed for revolutionary new solutions to the switching problem and much simpler mechanical design.

Stator

Compared to an Induction AC motor, the BLDC motor stator is made of laminated steel stacked to match the windings. Windings may be arranged into two patterns in a stator; i.e., a star pattern (Y) or delta pattern (nearly). The biggest difference between the two patterns is that at low RPM, the Y pattern offers lower torque, while at higher RPM, the upper pattern gives greater torque. This is because half the voltage is applied by undriven winding in the range configuration, thereby increasing losses and, in effect, torque and efficiency.

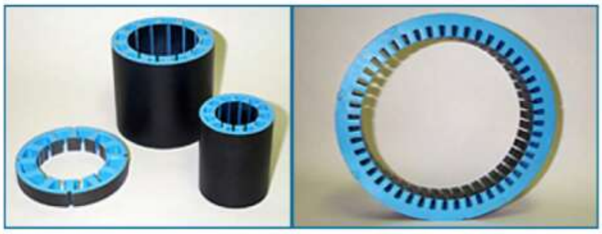


Figure 1.3: Stamping laminated steel-stator

As shown in Figure 2 Steel laminations in the stator may be either slotted or slotless. A slotless core has lower inductance, and thus can operate at extremely high speeds. Owing to the absence of teeth in the lamination stack, the cogging torque requirements often decrease, thus making them more suitable for low speeds too (when permanent magnets on the rotor and the tooth on the stator collide with each other instead owing to friction between the two, an excessive cogging torque develops and induces speed ripples). The biggest drawback to a slotless core is higher cost, as it takes more winding to cover the larger air gap.

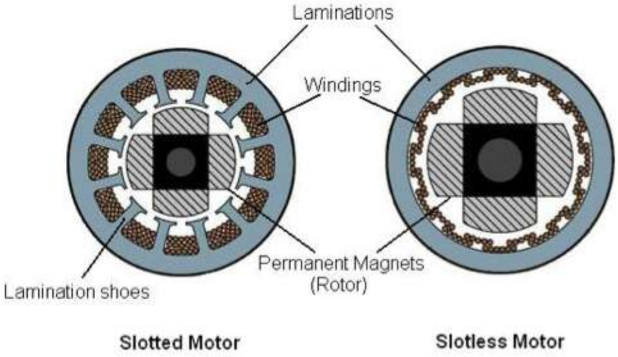


Figure 1.4: Drive with slot and slotless Motor

Proper selection of laminated steel and windings are critical for the motor performance in the stator construction. An unsuitable selection can lead to specific manufacturing problems, resulting in delays in launching and increased design costs.

Rotor

A typical BLDC motor rotor is made of permanent magnets. The number of poles within the rotor can vary depending on the application requirements. Increasing the number of poles will give a better torque but decrease the maximum speed possible..

Figure 1.5: 4 Poles and 8 pole-permanent rotor magnet

Another aspect of the rotor which determines the overall torque is the material used to create a permanent magnet; the higher the material's flux density, the greater the torque.

1.3.1 Basic Design Variations

Rotor Variations:

The rotor magnets exchanged in polarity and showed up at the rotor surface. While this is a prominent setup, unquestionably others are conceivable, as shown in Fig.

The rotor magnets rotated in polarity and showed up on the surface of the rotor. While this is a popular setup, many are unquestionably imaginable, as seen in Fig.

In Fig.(a), every other magnet is replaced with a back iron extension of the rotor. The flux from the inner south magnet poles is basically wrapped around to become the opposite magnet pole at the surface of the rotor. This rotor design does not deliver any efficiency benefits but can be less costly to manufacture because the number of magnets is reduced by half. This variance will result in a torque of significant reluctance. (b) shows a common type of PM rotor in the interior. The magnets here appear to be orthogonal to, rather than facing,electric steel propels the air gap and the magnet flux to the air gap. This configuration is popular when more efficient use of cheap ferrite magnets is required.

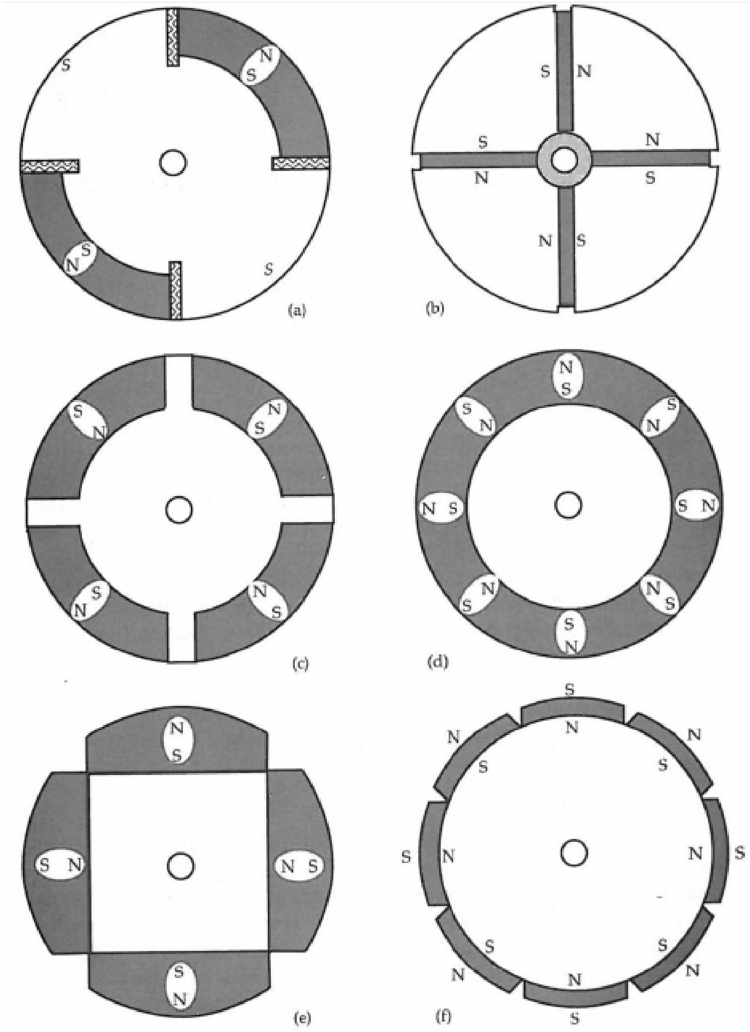


Figure 1.6: Rotor design variations.

In Fig.(c) electric steel replaces the non-magnetic spacer between the magnets. This steel has the function of adding a torque reticence part to the motor output. A major improvement of the motor output is possible if properly planned.

Figure(d) depicts a rotor with almost no spacers. In this case, the rotor is made of a single piece of bonded magnet material, which is magnetized with alternating magnet poles to replicate the basic configuration originally considered. This construction's principal benefit is its very low cost. , two the variants of the surface mounted magnet configuration under consideration are shown in Fig(e) and (f). Figure(e) displays magnets with loaf shapes and Fig. Shows opposite sided magnets. Both of these variants exist as potentially cheaper alternatives to the radial arc magnet which is ideal.

Stator Variations:

Variations in the design of stators are much more numerous and frequent compared with variations in rotors. There are many rising variations. In all cases the stator's purpose is to channel the air gap flux past the stator windings that hold the current.

Figure(a) represents the salient-pole or solenoid-winding construction. Short end turns are a advantage of this construction because windings are built around individual poles. The downside of this design is that each winding step doesn't connect with all rotor magnets simultaneously, which can contribute to lower efficiency.

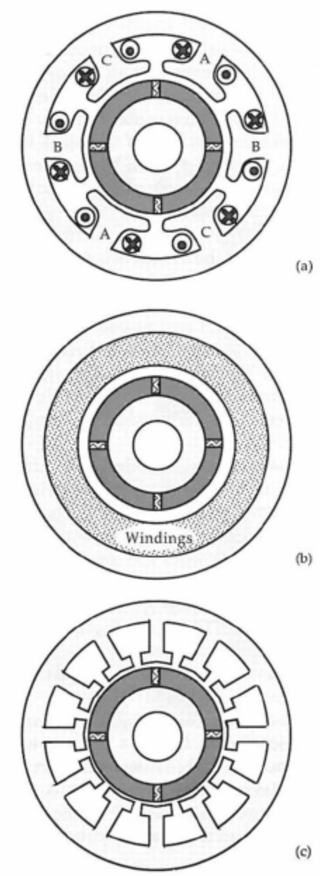


Figure 1.7: Stator design variations.

The full removal of the slots and the distribution of the stator windings within the stator back iron gives the slotless construction shown in Fig. **??**(b). This structure does not show a cogging torque but has many drawbacks. First, though there is more space for windings in this construction, The heat produced by the windings is harder to remove. Secondly, the absence of stator teeth makes the effective length of the air gap equal to the distance between the rotor surface and the stator at the rear iron.

The slotted structure is shown in Figure ??(c) Moreover, the slots here are not rectangular but have air gap shoes on them instead. These shoes are charged with reducing the difference in air gap permeability as a function of location decreases the cogging torque.

1.3.2 Operating Principle

PMBLDC operates on a concept similar to that of a PMSM motor, i.e. the Lorentz force law which states that where an existing carrier places a force in a magnetic field. The magnet will undergo an equivalent Because of reaction force the current carrier is stationary, while the permanent magnet pushes the opposite force. The actual carrying conductor is stationary in the case of PMBLDC motor.

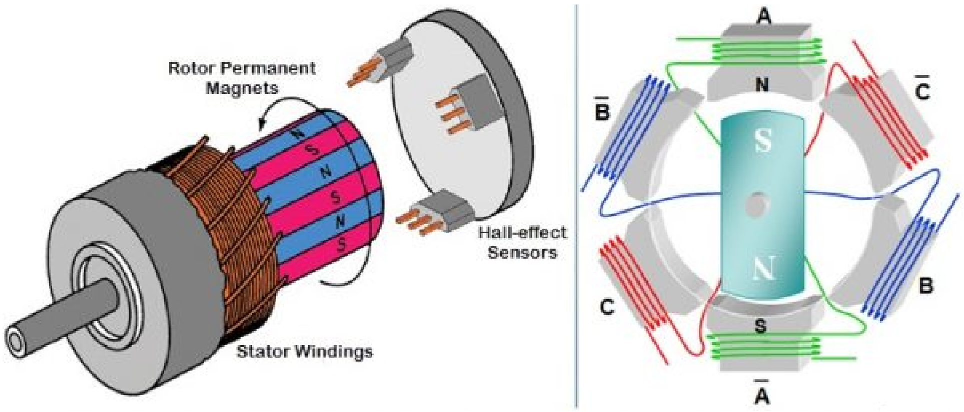


Figure 1.8: Operating principle of PMBLDC.

a supply source activates the stator coils electrically it becomes an electromagnet and begins to generate the uniform field within the air gap. While the source of supply is DC, switching produces a trapezoidal-shaped AC voltage waveform. The rotor continues to rotate due to the motion force between the electromagnet stator and the permanent magnet rotor.

Find the figure showing a motor stator excited in. As the north and south poles, the same winding energized as high and low signal with the switching of windings. The permanent magnet rotor aligns the north and south poles with stator poles allowing the rotation of motors.

See the figure showing an excited motor stator in. Like the north and south poles, with the switching of the windings the same winding energized as high and low signal. The permanent magnet rotor aligns the north and south poles with stator poles which allow motors to rotate.

1.4 Literature Survey

- This paper describes the use of Permanent Magnet DC Motor to raise up and down the car window glass by increasing speed and time customer need. Power window is a semi-automatic window that can be raised and lowered instead of using a hand turned crank handle by pressing a button switch. Here we use the PMDC motor to lift the window glass up and down in a simple way, with enough noise. For optimal velocity and torque for application of a window lift, using dc shunt motor. It is relatively easy to run manually. We 're going to create a PMDC Motor according to the Report. It is a DC motor brush that provides precise velocity control powered by Direct Strom. As the name implies, these contain permanent magnets that eliminate the need for external field current. This concept yields a smaller, lighter, power-efficient DC Motor brush and is the forms of the DC Motor. Because of its simplicity and reliability the brush DC Motor is a favorite in the automotive industry.

- High performance, quiet service, compact size, good reliability and low maintenance needs and permanent brushless DC magnet (PMBLDC) motors are the researchers' latest choice. Such motors are favored for many applications; however, most need Sensor less control of those motors. PMBLDC motor operations require sensing of the position of the rotor to the winding current.The Sensorless control includes determining the rotor 's position from the voltage and current signals that can be easily sensed. This paper introduces state of the art PMBLDC motor drives with sensorless control of those motors.

- It is very important to pick and build the motor for electric and hybrid vehicles as the motor in this application should have high power density, higher efficiency, fit within a li room and high heat removal capability. One of the better options for this type could be an axial flux brush with less DC motor. In this paper the study selects a smaller DC motor with an axial flux net. A preliminary design is coming based on magnetic circuit equations and power equilibrium. Then it conducts the preliminary definition of Finite Element Analysis. The FEA finds that the draft design can be fine-tuned. The key features are the magnet shape and the tube and tube shape are slot width.The various shapes of the magnets are analyzed, and an ideal shape is proposed that decreases the torque of the cogging. The efficiency of the engine (refined design) found by FEA is compared with the stated values and found that the designed engine meets the requirements. The key improvement is the shape of the magnet, and the shape of the slot and slot width is small. The different shapes of the magnets are studied, and an optimal form that reduces the torque of the cogging is suggested. The motor output obtained from FEA (refined design) is compared with the specified values and it has been obtained that the designed motor meets the needs.

- The aim of this work is to develop a competitive alternative design topology for a small permanent dc magnet (PMDC) motor that is used in automotive applications (in terms of power density). A real industrial motor is initially evaluated, red and siated while its dimensions and related supplier data are considered a benchmark. In turn, the custom developed program proposes a redesigned configuration regarding structural (stator, rotor, magnet) geometry and magnet material. The resulting geometry was obtained using a restricted optimization algorithm to minimize overall volume and Commercial Finite Element Method (FEM) analysis software was further tested. The new model is comparable with the benchmark engine, too. Last but not least, work into FEM has been used to check thermal behaviour. Overall findings show that the energy density and efficiency of the proposed topology have increased significantly, although the cost remained small.

- This paper introduces a computer-aided method of design (CAD) for a permanent brushless dc motor (PM BLDC) mounted on a radial-flow board. It is believed that style variables such as airgap flux density, slot electric charge, winding factor, stacking factor, stator current density, space factor, magnet fraction, slot fraction, back iron stator flux density, etc. respond to the directions and justifications for this. The basic sizing equations are derived from the design algorithms and used for them. Using the produced computer program, three distinct motors are modelled. The model engines are tested by finite element (FE) and the results are dealt with.

- Bearingless motors (BelMs) were proposed and developed which can perform magnetic levitation rotation without mechanical contact. In general, distributed winding system is implemented in high speed and high output BelMs to prevent iron loss, and it achieves a high power density with the use of neodymium sintered permanent magnet (Nd sintered PM). However, the drop in output power is caused by the long coil end of the distributed winding system, as the primary mode of bending under high speed rotation restricts a shaft length. Additionally, because of its high conductivity, eddy current loss in the Nd sintered PM occurs quickly and the rising temperature in a rotor is difficult to achieve continuing high speed and high performance operation. Hence, this paper proposes a high speed and high power density BelM using a concentrated winding stator and a permanent neodymium bonded magnet (Nd bonded PM) to counteract the reduction in output power caused by the coil end and the loss of eddy current produced in PM. This paper also shows the results of the study of different BelM models using distributed winding structure, concentrated winding structure, Nd sintered PM, and Nd bonded PM. The interpretation of these findings is discussed in more depth and clarityon the feasibility of the program proposed

- This paper presents the design, simulation and analysis of the BLDC motor for automotive applications in three step. BLDC motor finite element analysis (FEA) is performed to validate system flux relationship functionality. The BLDC engine proposed is modelled and simulated with MotorSolve. The modeling software tool's simulation results will focus on the torque distribution and the magnetic flux density. The BLDC motor is modelled using MATLAB / SIMULINK to control the PMBLDC motor's dynamic characteristics.

- Use rare earth magnets which rely on permanent magnet technology for the vast majority of motor solutions. They offer a good combination of high specific torque and low losses which justify their choice in most applications. The key challenge is the relatively high cost of PM materials: this technology does not provide the best long-term solution for use with electric vehicles. Thus it has become imperative to search for alternative solutions, such as rare earth free machines or reduced rare earth PM machines. Induction motors, gear lid alternatives, While care must be taken during motor sizing and electrical steel selection to meet the challenging specifications and avoid an increase in the cost of the device. The advancement of rare earth free traction technologies would lead to greener transportation through the provision of new solutions that are not dependent on critical sources and the use of broad production capacities for electric motors.

- This paper discusses the design aspects of an active electromagnet suspension system, combining a brushless permanent tubular magnet actuator (TPMA) with a passive spring, for automotive applications. This system provides additional slit and protection during cornering and braking by performing active roll and pitch control. In addition, irregular cities on the route can be eliminated, thus increasing comfort for passengers traveling. The actuator's static and dynamic parameters are drawn from the tests.The electromagnetic suspension is mounted on a quarter-car test platform and improved performance is calculated using roll control and compared to a passive commercial device. An alternative design is proposed using a slotless external tubular magnet actuator that satisfies the cost, thermal and volume specifications obtained.

- An internal permanent magnet (IPM) engine designed for an electric vehicle is a fascinating engineering issue when calculating performance. Due to the low power, such a device has very high electrical and magnetic charges, reaching up to a few hundred kW. The hitting of torque density and very high power is a recent subject. Not only is the motor output critical at the measured currents but also under high overload (intermittent duty). Analyzing the IPM motor to predict its capabilities requires quick and precise procedures. This paper has some implications for it. An example is an IPM engine with a size similar to that of commercial vehicle machines.

Chapter 2

Permanent Magnet Motors in Automotive Applications

2.1 Application of Motors in Automotive Sector

Electric motors find a wide variety of applications in the automotive sector. A car fitted with a feature is increasingly favored. Luxury car manufacturers are increasingly paying attention to feature enhancement in order to improve safety and comfort during the journey. Accordingly, following motors are used in automation sector architecture.

- seat adjustment motor
- power window motor
- wiper motor
- power steering motor
- lift gate motor

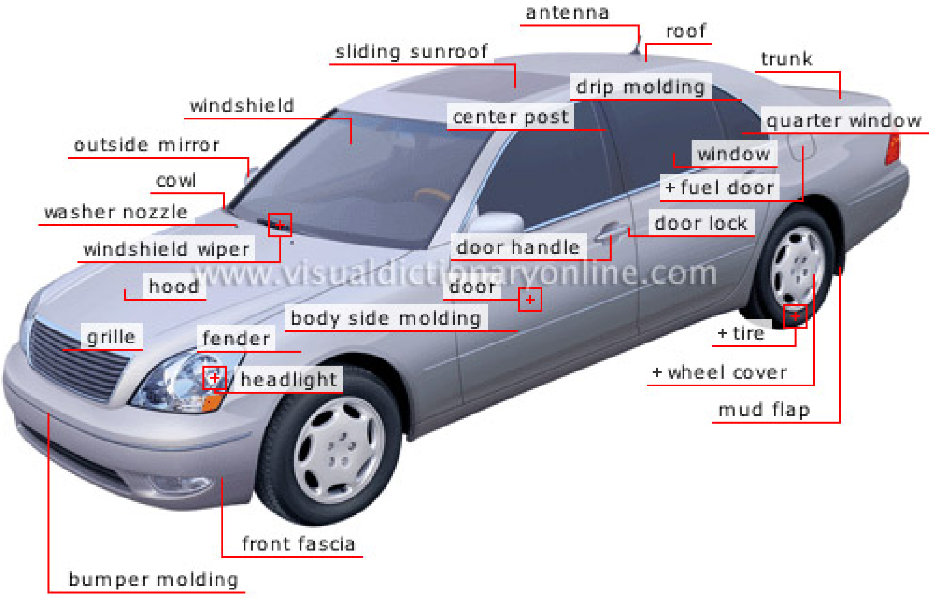


Figure 2.1: Car Feautures in Automotive Applications

The work done in this project aims to enhance the functionality of power windows by exploring the design possibilities that PMBLDC motor provides.

2.1.1 Power steering motor

The electric power steering motor uses an electric three-phase motor driven by a DC voltage modulated by the pulse duration. The motor is brushless and has a range of 9 to 16 volts for operation. Engines for faster and more accurate torque application at low Rpm.

The motor uses a rotational sensor, which defines the motor's location. In certain systems the end stops of the steering system must be learned if the module is removed or the toe has been adjusted so that the motor does not move the rack beyond the maximum steering angle. This may be an additional step alongside the steering angle sensor calibration. You may plug the motor inside the steering rack or frame. Many cars today use engines that are mounted on the steering gear frame, or on the rack's opposite end.

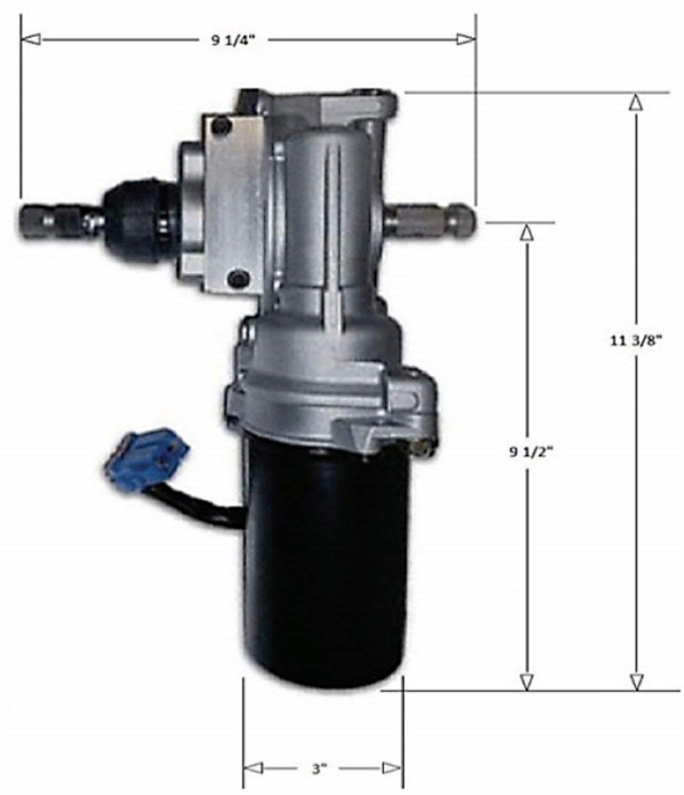


Figure 2.2: Power Steering Motor

2.1.2 Seat Adjustment motor

An auto power seat is a front seat that can be changed with a switch or joystick, and a series of small electric motors. For this option, many cars do have driver seat controls but nearly all luxury cars have power controls for front passenger seat. Power seats, in addition to front and aft modifications, can be elevated or lowered and modified to match driver or passenger comfort. Some power seats require passengers to flip or press a button to change the lumbar seat or recline in the rear seat.

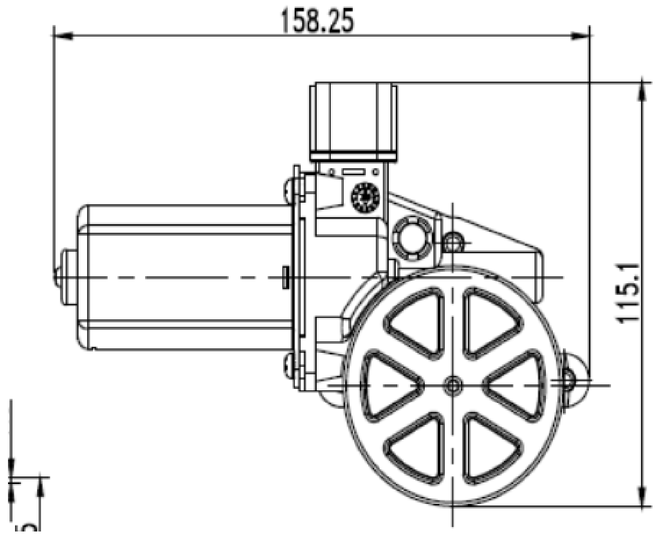


Figure 2.3: Power Seat Adjustment Motor

2.1.3 Lift gate motor

A typical feature of a lift gate is that it requires a platform that can be raised and lowered so that a load can be loaded or unloaded from a vehicle and then stored. ... One type of lift gate has an electric motor, which raises and lowers the platform through a mechanical mechanism.

Figure 2.4: Lift Gate Motor

2.1.4 Wiper motor

In the wiper network, wiper motors are machines that operate on a power supply to drive the wiper blades in smooth motion. Like other engines, the wiper motor constantly rotates in one direction that is transformed into a back and forth motion.

Figure 2.5: Wiper Motor

2.1.5 Power Window Motor

In this power window application PMBLDC Motor is used to glass up and down and the car window glass by increase the speed and decrease the time.

Figure 2.6: Power Window

Power window is a semiautomatic window that can be elevated and lowered by pressing a control button. Hand turned handle had been used in earlier times. Here PMBLDC motor is used with the correct noise to elevate the window glass up and down in a simple way. For a desired speed and torque requirement, using dc shunt motor for window lift application. It is relatively easy to run manually. As required we will be building a PMBLDC motor. It provides precision control of the direct current powered by rpm. As the Title suggests, These include permanent magnets which eliminate the need for external field current. This design produces a smaller, lighter, energy-efficient DC Motor brush, which is the DC Motor types. The DC Motor brush is especially favored in the automotive industry, as it is both easy and inexpensive. Many car manufacturers use these for power windows, seats etc..

The Power Window Motor with some unique features that make them more user-friendly has been selected from five motors for this project.

The work done in this project aims to enhance power window functionality by exploring the design possibilities offered by PMBLDC motor.

2.2 Permanent Magnet Motor for Power Window Application

- The Power window is an simple device for opening and closing vehicle windows where appropriate.
- Quickly open and close the window by simply clicking a button.
- Power windows are one of the most convenient vehicle features that let you concentrate on the route.
- They allow physically disabled people to have better access and control of the car.
- It also blocks children's access while they're in the back seat and want to roll the window.
- The most common trigger is defective engines and regulators, since they are used more often than other vehicle parts.

- Power windows do not show any warning signs before failure or failure
- Regulator or moving mechanism Power window motor Switches to control window

2.3 Operation of Power Window Motor

- Power windows are usually inoperative when the car is not running. This is essentially a feature of health.
- Electricity windows would be easy to control when the ignition is shut off, but this would also make the vehicle much harder to steal.
- Before opening a passenger door, several systems have the option of adding power to the windows and then removing the power of the window.
- Hydraulic drive systems could lower the windows at rest, because the hydraulic system pressure was only released to lower the window.
- An electrically operated pump was required to raise the windows, and pressure was applied to the appropriate cylinder.
- These devices also had per cylinder pressure row. The device could also leak gas because of its size.

2.3.1 Power Window Specifications

- Voltage : 12 VDC
- Rated Speed: 60 RPM
- Rated Torque: 2.9 Nm
- Rated Current: 15 A at 12 V
- Stall Torque: 9.8 Nm
- Stall Current: 28 A at 12 V

This motor is intended to drive the window of the car as the name says It is tested to drive the window of the car: Up and Down for 8 seconds, withstand 10,000 times Not intended for continuous driving without running.

2.4 Load Characteristics of Power Window Motor

Power window motors are devices that are installed inside the door of the car which control the function of window glass to allow them to go up and down. The window ceases to work in whatever position it was in when the power window motor failed. If the window is open when the engine fails, this may pose a security problem.

Basic Characteristics:- The Power Window motor has four mounting spot area. The working voltage is 12 Volt DC.

No Load Characteristics:- The no-load speed or speed is 95 rotations per minute (rpm) when no torque is applied to the motor shaft, and the no-load current is less than 1.5 amperes.

Stall Characteristics:- The stop torque or minimum torque required to stop the entire spinning motor shaft or to stop the motor is less than 8 units or pound-feet (N.m) and the stall current is less than 20 ampers..

The rating carried out of Permanent magnet Brushless Dc Motor for power window application are as following:-

2.5 Specifications:-

- Voltage : 12.5 V
- Current : 4.2 A
- Speed : 50 rpm
- Efficiency : 60%
- Power : 30 W
- Max Torque : 5.5 Nm
- Dimension : 158*115*31 mm

Detailed analysis of above rating of the permanent magnet motor will be done in the next chapter.

Chapter 3

Design of Permanent Magnet Motor for Power Window Application

PM motors are typically of a radial-flux type. The explanation for this is that the manufacturing is straightforward and constructed using slotted stators with regular round radial laminations, in order to optimize the electrical charge due to the use of the slots. There are also several examples of axial-flux systems being used. In fact, axial-flow systems may also be considered, but here the emphasis will be on laminated radial-flow motors, since these are the majority of brushless PM motors.

3.1 Sizing Equations

3.1.1 Stator Design

- **Power Developed:**

$$P = Tw \tag{3.1}$$

$$T = P/w \tag{3.2}$$

- **Length and Diameter:**

$$L = \sqrt[3]{\frac{4T(AspectRatio)^2 \times 10^{-3}}{\pi K T_{RV}(SplitRatio)^2}} \tag{3.3}$$

$$D_{so} = \frac{L}{AspectRatio} \tag{3.4}$$

- **Calculation of No. of Turns per Phase:**

$$T_{ph} = \frac{\pi D_{ro} a_c}{4 I_{ph}} \tag{3.5}$$

$$I_{ph} = \frac{P}{V\eta} \tag{3.6}$$

$$a_c = \frac{K T_{RV}}{2Bg} \tag{3.7}$$

- **Total No. of Conductors:**

$$Z_{ss} = \frac{6T_{ph}}{N_s} \tag{3.8}$$

- **Area of Conductor:**

$$a_s = \frac{I_{ph}}{\delta} \tag{3.9}$$

- **Calculation of Slot Dimensions:**

$$A_s = \frac{Z_{ss} a_s}{K_{cp}} \tag{3.10}$$

$$A_s = w_{sb} \times ShankLength(d_1) \tag{3.11}$$

$$d_1 = SlotDepth(d_s) - \alpha_{sd} w_{st} \tag{3.12}$$

- **Calculation of Width of Stator & Width of Stator Teeth:**

$$w_{sy} = \frac{A_{sy}}{L_i} \tag{3.13}$$

$$w_{st} = \frac{A_t}{K_{st} L} \tag{3.14}$$

- **Inner Radius of Stator:**

$$R_{si} = \frac{D_{si}}{2} \tag{3.15}$$

$$D_{si} = D_{ro} + 2l_g \tag{3.16}$$

3.1.2 Rotor Design

- **Diameter:**

$$D_{ro} = D_{SO} \times SplitRatio \tag{3.17}$$

- **Calculation of Width of Rotor Yoke :**

$$w_{ry} = \frac{\phi_g}{2B_{ry}K_{st}L} \tag{3.18}$$

- **Inner Radius of Rotor:**

$$R_{ri} = R_{ro} - lm - W_{ry} \tag{3.19}$$

$$D_{ri} = 2R_{ri} \tag{3.20}$$

3.1.3 Performance Estimation

$$R_s = \frac{\rho n_s^2 L}{K_{cp}A_s} \tag{3.21}$$

$$R_e = \frac{\rho \phi n_s^2}{2K_{sp}A_s} \tag{3.22}$$

$$R_{ph} = N_{sp}(R_s + R_e) \tag{3.23}$$

$$P_{cu} = 3I_{ph}^2 R_{ph} \tag{3.24}$$

$$V_{sc} = \pi(R_{so}^2 - R_{sb}^2)L_i \tag{3.25}$$

$$W_{sc} = V_{sc} \times D_{sc} \tag{3.26}$$

$$V_{st} = [\pi(R_{sb}^2 - R_{si}^2) - N_s A_s]L_i \tag{3.27}$$

$$W_{st} = V_{st} \times D_{st} \tag{3.28}$$

$$W_{STATOR} = W_{st} + W_{sc} \tag{3.29}$$

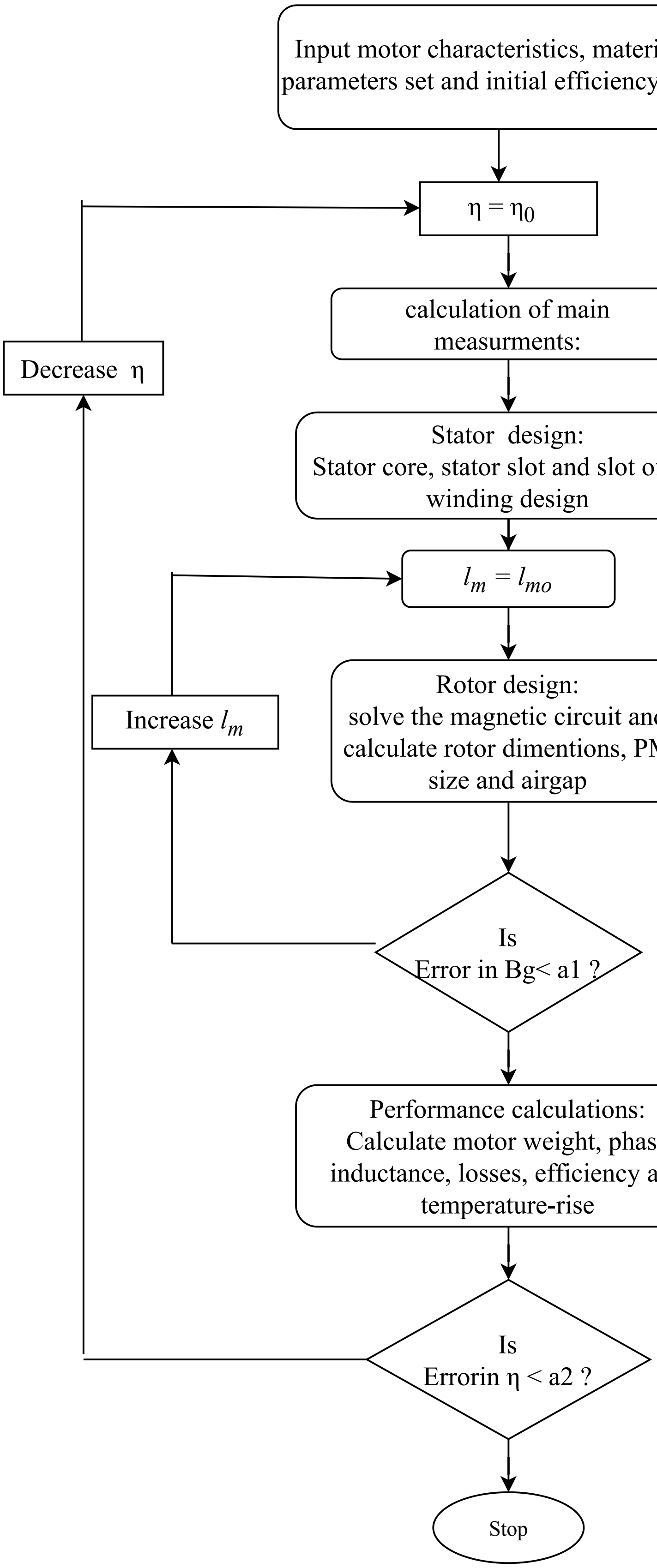
$$IronLoss, W_i = W_{STATOR} \times IronLoss_{Specific} \tag{3.30}$$

$$\eta = \frac{P_{out}}{P_{out} + P_{cu} + W_i + W_{Stray}} \tag{3.31}$$

3.2 Flowchart for PMBLDC Design

By using the equations discussed above in the subsections, it is possible to carry out the design parameters and the performance estimate that involves stator and rotor design, output, loss and cost estimates for the model whose ratings are given in tables.

This motor design involves various steps that are illustrated or shown by means of a flowchart shown in the figure. This figure offers a simple view and interpretation of the steps that are involved in PMBLDC design or CAD.


Input motor characteristics, materials, parameters set and initial efficiency (η0)
η = η0
calculation of main measurments:
Decrease η
Stator design: Stator core, stator slot and slot of the winding design
lm = lmo
Increase lm
Rotor design: solve the magnetic circuit and calculate rotor dimentions, PM size and airgap
Is Error in Bg< a1 ?
Performance calculations: Calculate motor weight, phase inductance, losses, efficiency and temperature-rise
Is Errorin η < a2 ?
Stop

Steps of flowchart shown in figure are briefly discussed here below:

- Permanent Magnet Brushless DC motor design is a two-loop cycle with varying feature call.
- The inputs are engine specifications, model type, material types and other presumed design details.
- The outer loop shall set the expected output, and correct it.
- Initially, motor output is presumed.
- The approach illustrated in the figure designs the engine and the actual output is measured. The correction loop is active until the desired output is not obtained.
- The interior loop is designed to reduce the difference between the air gap's predicted and real flux densities by similarly increasing the magnet(lm) length.
- The longitude of the magnet varies until the difference between the two is less than the limit specified.
- The measurement of the principal dimensions, the design of the stator, the permanent magnet, the design of the rotor and the output measurement are the four main stages of the construction.

3.3 Design Specification

Properties	**Value**
Power	30 W
Speed	50 rpm
Rated Torque	5.73 N-m
No. of Poles	4
No. of Slots	12
Terminal Voltage	12.5 V

Table 3.1: Basic Machine Ratings

3.4 Assumed Design Variables

This model is constructed using the steps shown in Figure,which is the flowchart for the Interior Permanent Magnet Brushless DC Motor according to the ratings given in the table and the other properties / details provided in the table.

Properties	**Value**
Material	$M19 - 29Ga$
Magnet Type	$NdFeB$
Air-gap	0.5 mm
Space Factor	0.4
Current Density	5.01 A/mm^2
Flux Density in Teeth	1.7 T
Flux Density in Yoke	1.5 T

Table 3.2: Initial design Assumptions.

3.5 Design Outcomes

Properties	**Value**
Outer Diameter	115 mm
Stack Length	115.2 mm
Rotor Diameter	57.6 mm
PM Thickness	5 mm
PM Width	16.9 mm
Stator Back Iron Depth	11 mm
Input power	50 W
Output power	30 W

Table 3.3: PWM Analysis Results

3.6 FE Analysis

Performance

Properties	**Value**
Loss - Total	20.7 W
Loss - Winding	18.6 W
Loss - Iron	34.8 W
Efficiency (%)	60
Rotor core mass	1.41 kg
Rotor magnets mass	0.671 kg
Stator core mass	4.76 kg
Stator winding mass	1.57 kg
Total Weight	8.47 kg

Table 3.4: FEA Output

FE Model:

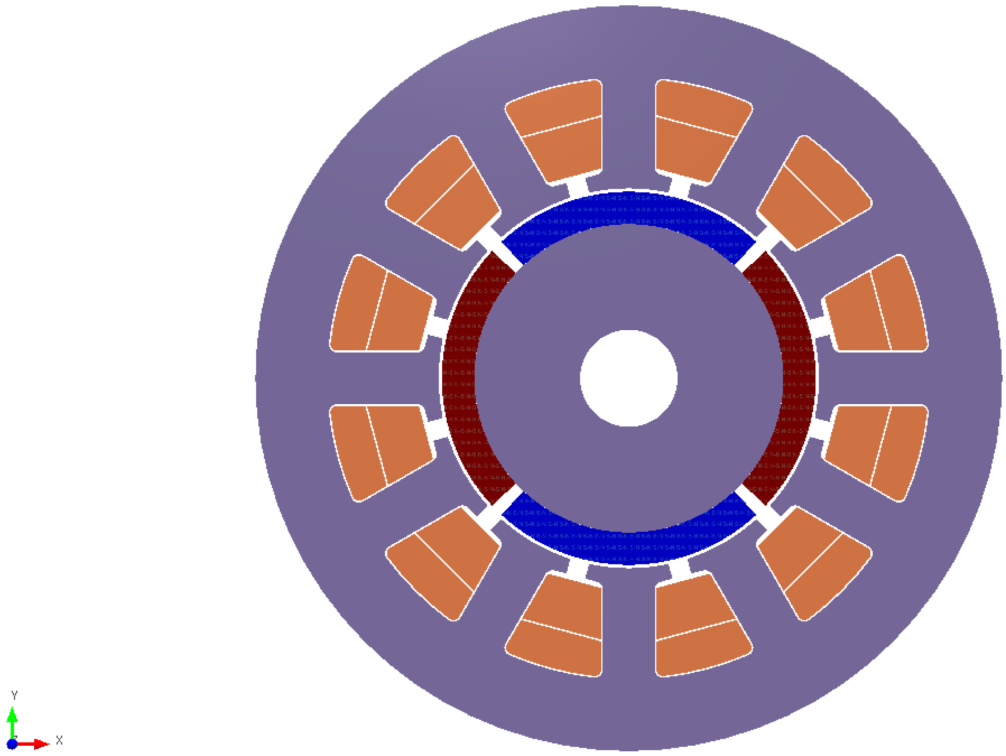


Figure 3.2: 2D View of PMBLDC Initial Design for 30W, 50rpm model.

Flux Density And Flux Function Plot:

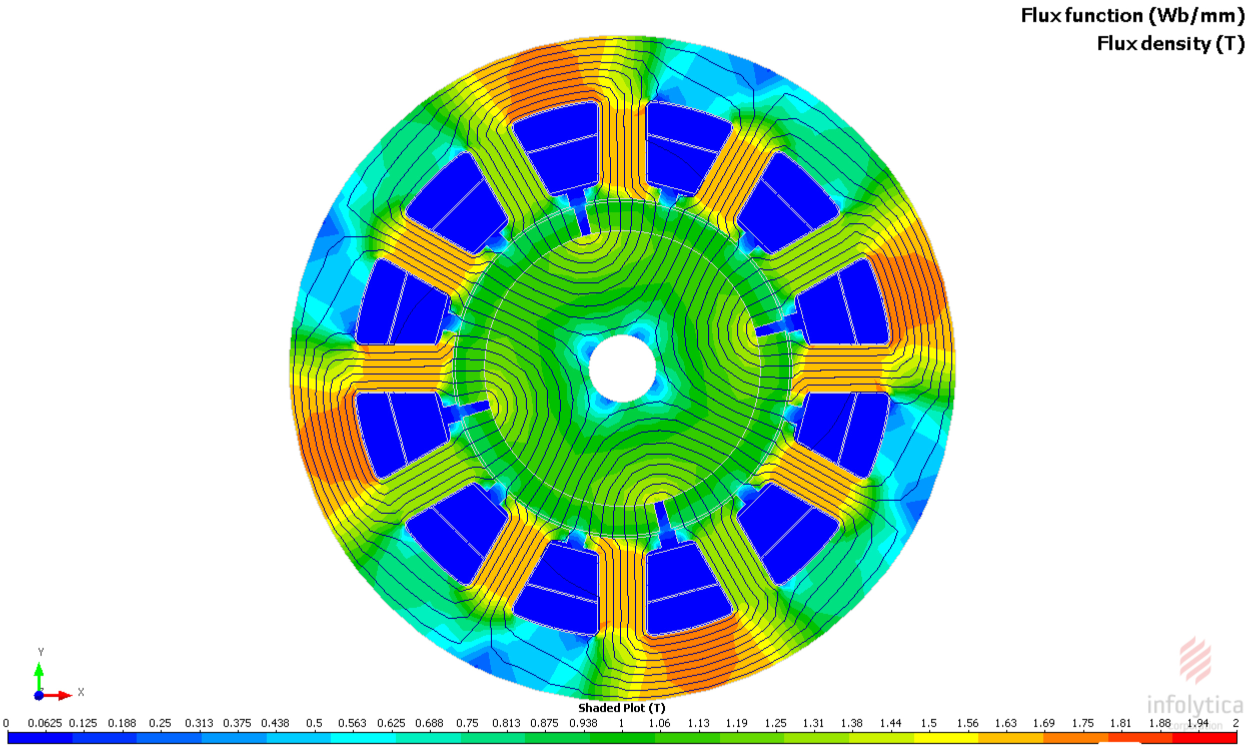


Figure 3.3: Instantaneous Field Plot 30W 50rpm Motor

Torque And Cogging Torque Curves:

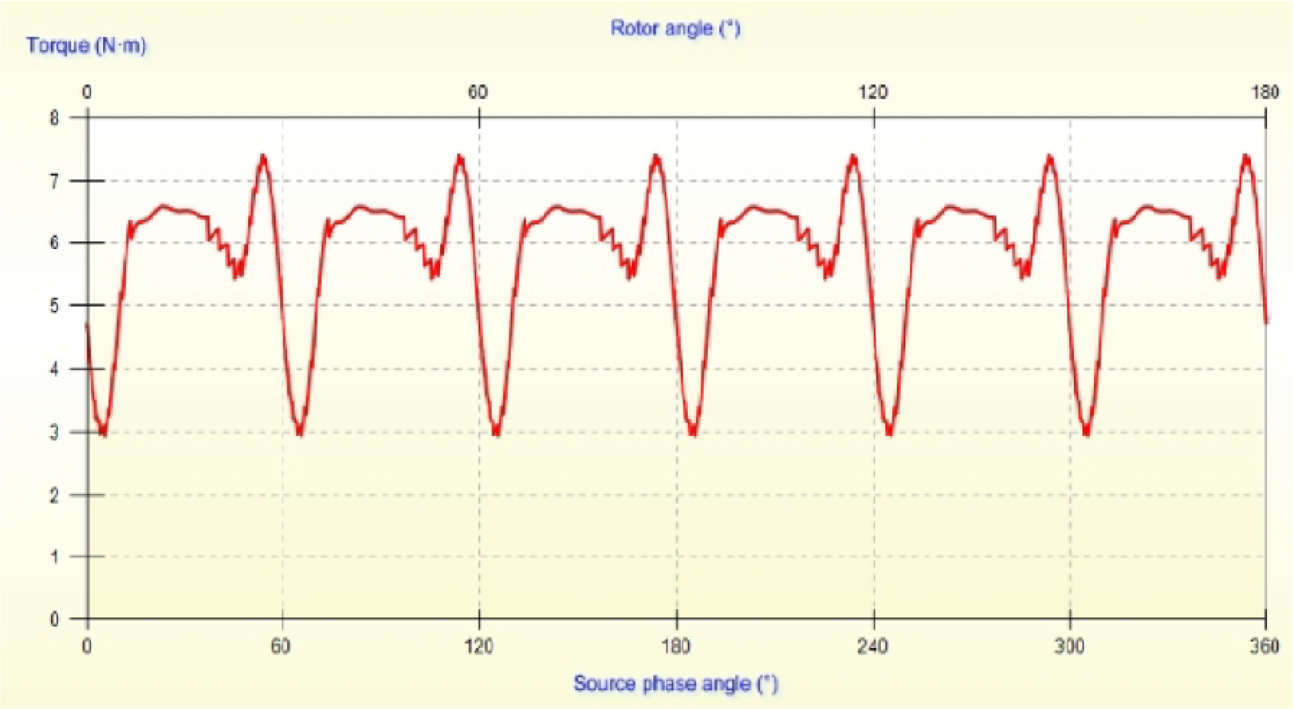


Figure 3.4: Torque of 30W and 50rpm motor

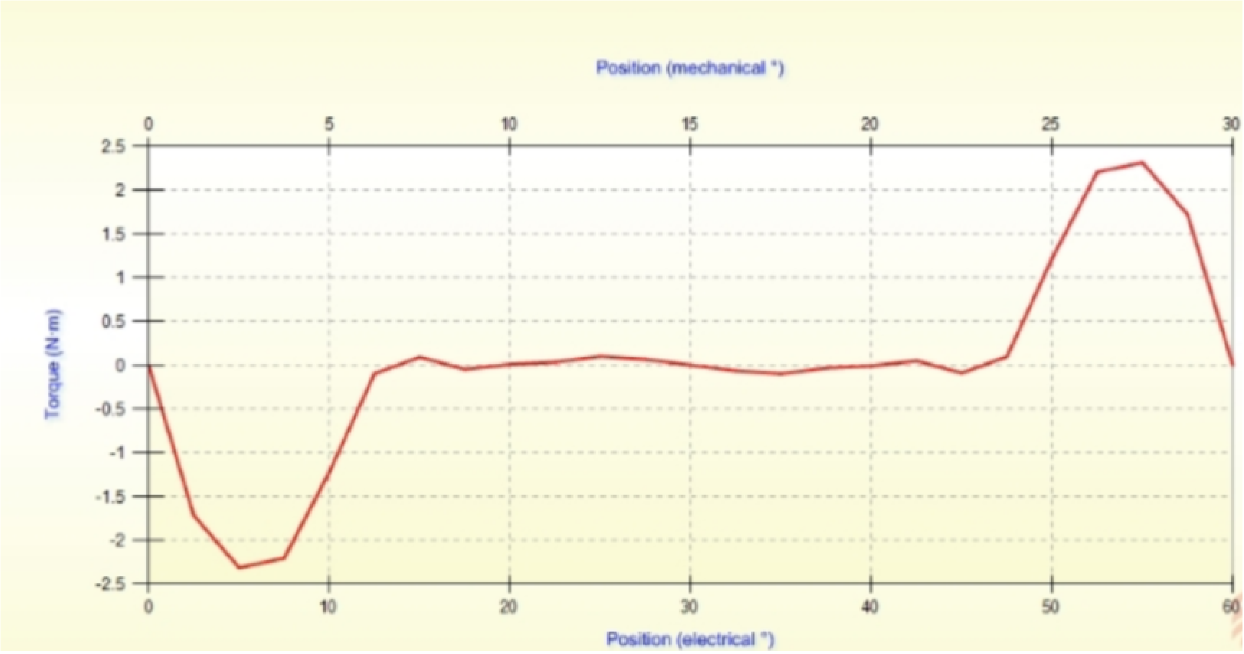


Figure 3.5: Cogging Torque of 30W and 50rpm motor

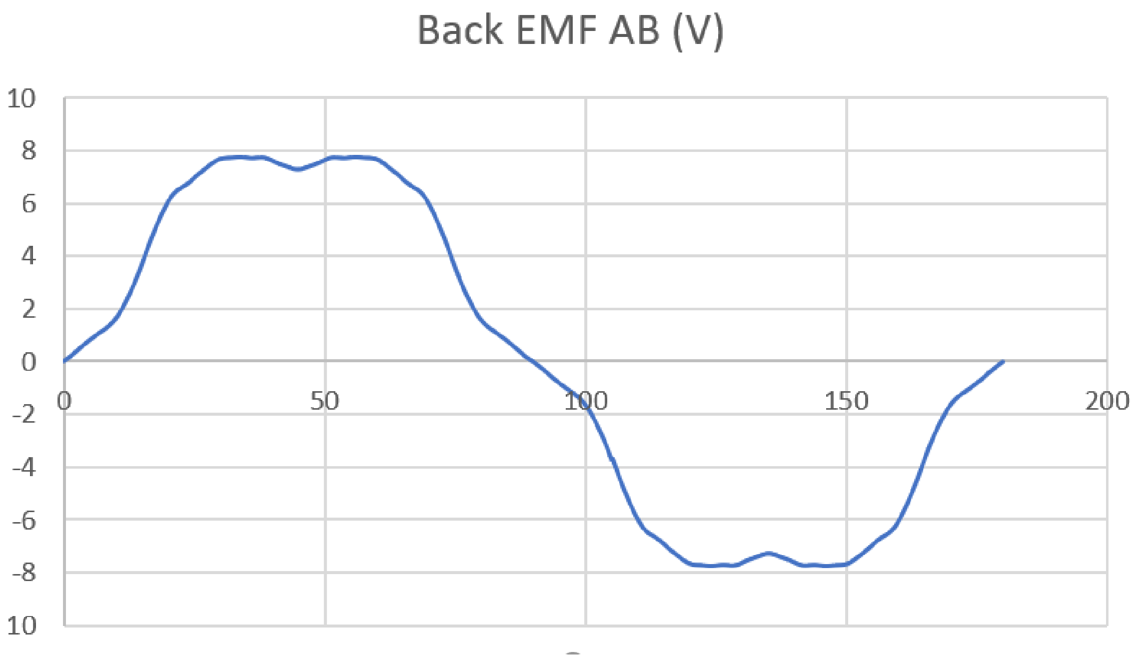


Figure 3.6: Back Emf of 30W and 50rpm motor

Chapter 4

Design Improvement of Permanent Magnet Motor for Power Window Application

4.1 Part 1 :- Size Reduction

Because of size reduction, I have achieved 12 W performance in this project by changing the M19 Material instead of Hiperco 50A Material and also the magnet thickness size in the rotor and outer diameter. Magnet thickness on motor torque is affected.

4.1.1 Hiperco Material

Until now reference model of ratings 30 W, 50 rpm is developed using motor solve software. Now new improved designs are discussed in this chapter. With the same ratings used for reference model Motor-Solve program is again being used to build new model with improved performance using material from Hiperco instead of material from M19. The material used for Hiperco 50A displays clear advantages in many respects:

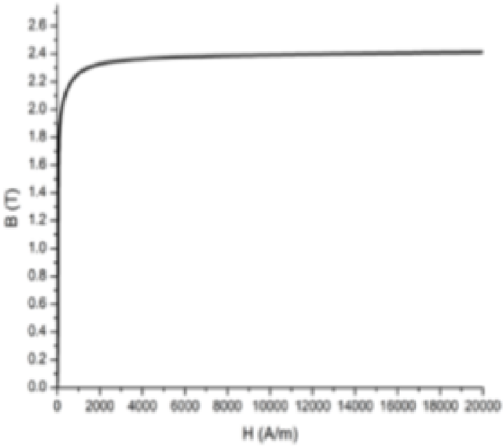


Figure 4.1: B-H Curve for Hiperco 50A material

- Hiperco 50A is a soft magnetic alloy of iron-cobalt-vanadium that exhibits high magnetic saturation (2,3 T).
- Have greatest permeability
- Low coercive force
- Low loss to core.

4.1.2 Design Specification

Properties	**Value**
Material	$Hiperco\ 50A$
Magnet Type	$NdFeB$
Air-gap	$0.5\ mm$
Space Factor	0.4
Current Density	$5.01\ A/mm^2$
Flux Density in Teeth	$2.3\ T$
Flux Density in Yoke	$2\ T$

Table 4.1: Initial design Assumptions.

4.1.3 Design Outcomes Using Hiperco

Properties	**Value**
Outer Diameter	95 *mm*
Stack Length	80 *mm*
Rotor Diameter	50 *mm*
PM Thickness	4 *mm*
PM Width	17.2 *mm*
Stator Back Iron Depth	8 *mm*
Input power	50.5 *W*
Output power	30.2 *W*

Table 4.2: PWM Analysis Results

4.1.4 FE Analysis Approach

Performance:

Properties	**Value**
Loss - Total	17.4 *W*
Loss - Winding	21.3 *W*
Loss - Iron	25.8 *W*
Efficiency (%)	66
Rotor core mass	1.12 *kg*
Rotor magnets mass	0.421 *kg*
Stator core mass	3.04 *kg*
Stator winding mass	1.15 *kg*
Total Weight	5.731 *kg*

Table 4.3: FEA Output

Model:

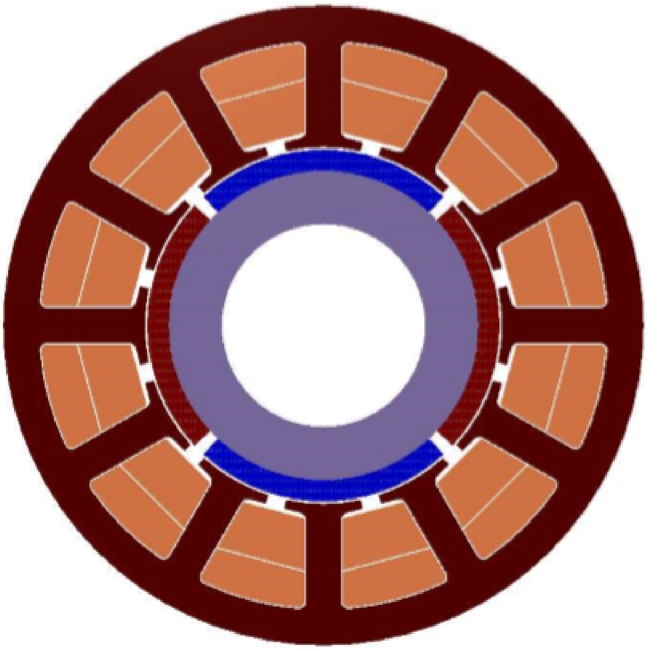


Figure 4.2: Improved Design of 30 W , 50rpm motor model.

Flux Density And flux Function plot:

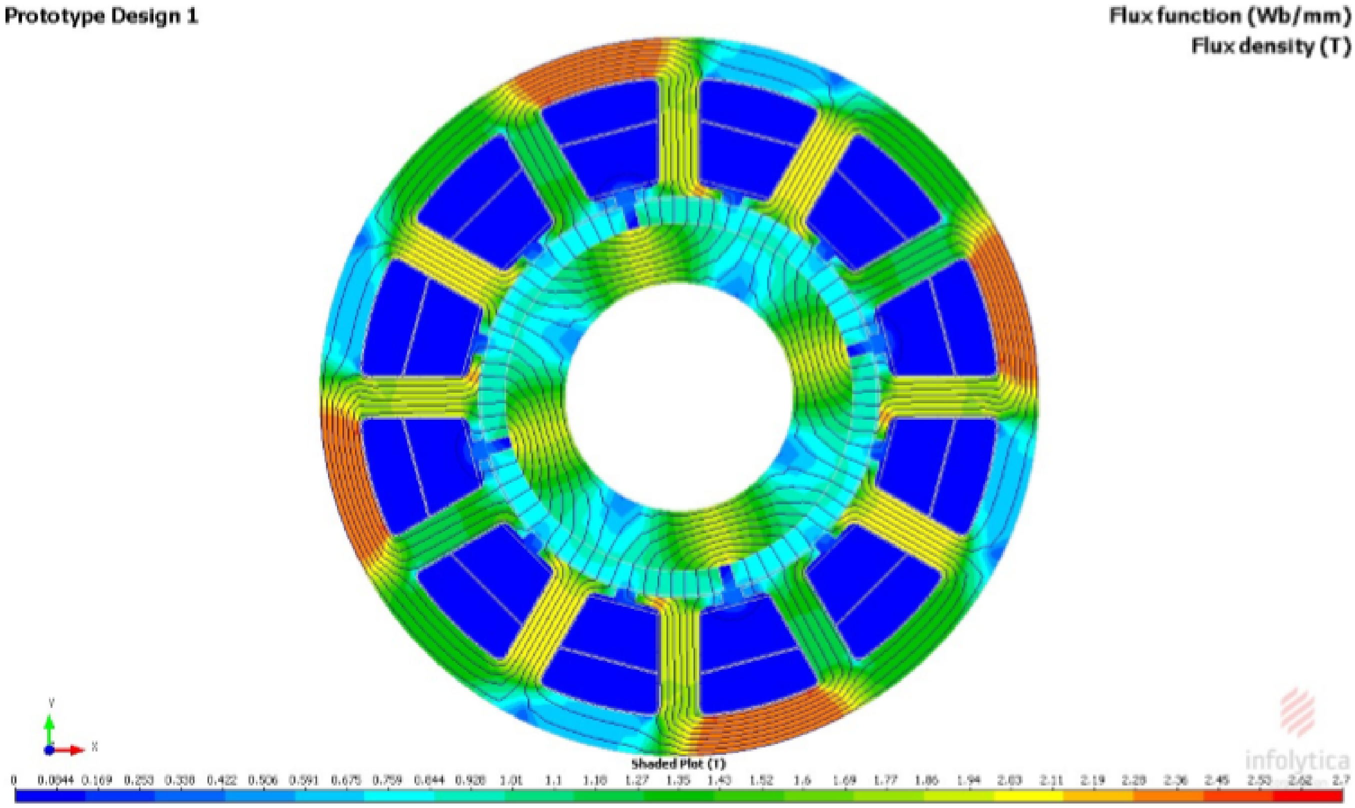


Figure 4.3: Instantaneous Field Plot for 30 W , 50rpm motor model.

Torque Curves:

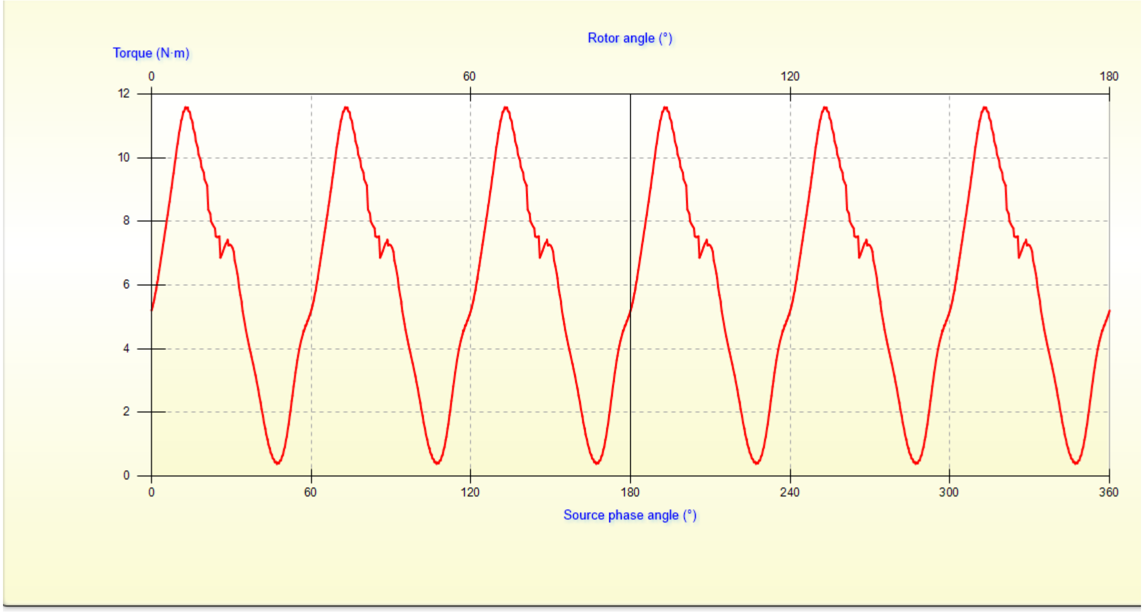


Figure 4.4: Torque profile of 30 W, 50rpm motor design.

Cogging Torque:

Figure 4.5: Cogging Torque profile of 30W, 50 rpm motor design.

Backemf Profile:

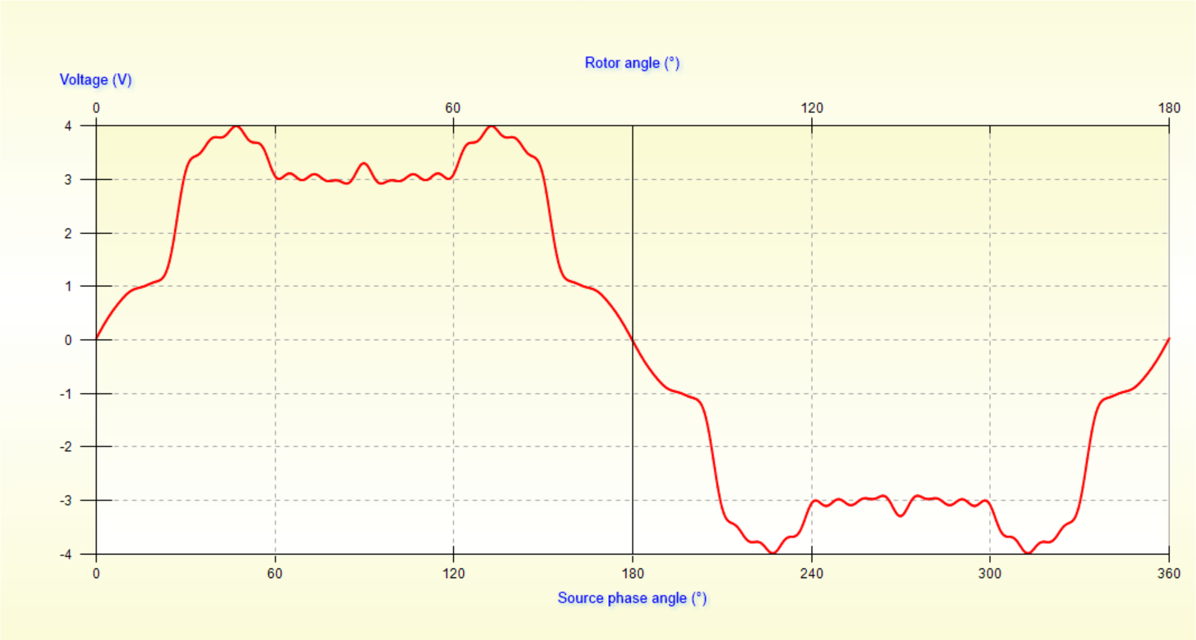


Figure 4.6: Backemf profile of 30 W, 50rpm motor design.

4.2 Part 2 :- Cost Reduction

Because of cost reduction, I have achieved 12 W performance in this project by changing the M19 Material instead of M43-24 Gages Material and also the magnet thickness cost in rotor and outer diameter. Magnet thickness on engine torque is affected.

4.2.1 M43 - 29 Gage Material

M43 (Non-oriented electrical steels) are magnetic saturated silicon steels (1.6-1.9 T), and magnetic properties are essentially the same in all directions of the plane's magnetism, as well as mean core losses of have low.

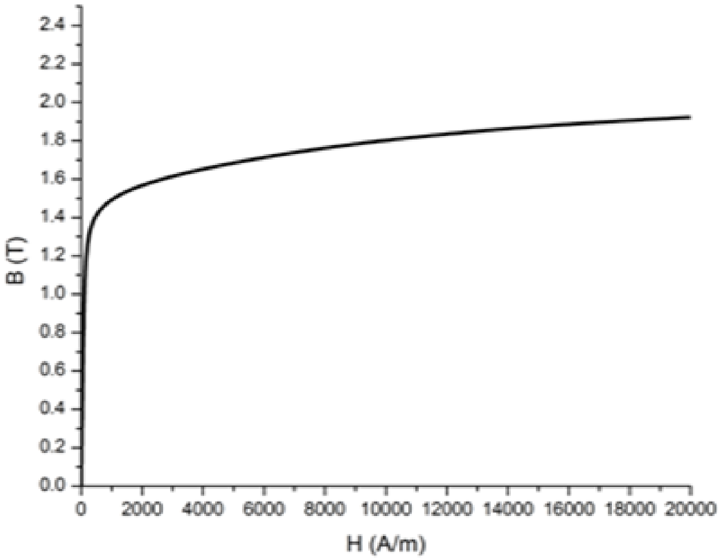


Figure 4.7: B-H Curve for M43 -29 Gage material

4.3 Design Specification

Properties	Value
Material	$M43-29\ Gage$
Magnet Type	$NdFeB$
Air-gap	$0.5\ mm$
Space Factor	0.4
Current Density	$5.01\ A/mm^2$
Flux Density in Teeth	$1.9\ T$
Flux Density in Yoke	$1.7\ T$

Table 4.4: Initial design Assumptions.

4.3.1 Design Outcomes Using M43-29 Gage

Properties	Value
Outer Diameter	$100\ mm$
Stack Length	$85\ mm$
Rotor Diameter	$52\ mm$
PM Thickness	$5\ mm$
PM Width	$18.2\ mm$
Stator Back Iron Depth	$9.5\ mm$
Input power	$51.1\ W$
Output power	$30.2\ W$

Table 4.5: PWM Analysis Results

4.3.2 FE Analysis Approach

Performance:

Properties	**Value**
Loss - Total	18.2 W
Loss - Winding	19.3 W
Loss - Iron	28.6 W
Efficiency (%)	56
Rotor core mass	1.22 kg
Rotor magnets mass	0.571 kg
Stator core mass	3.12 kg
Stator winding mass	1.31 kg
Total Weight	6.221 kg

Table 4.6: FEA Output

Model:

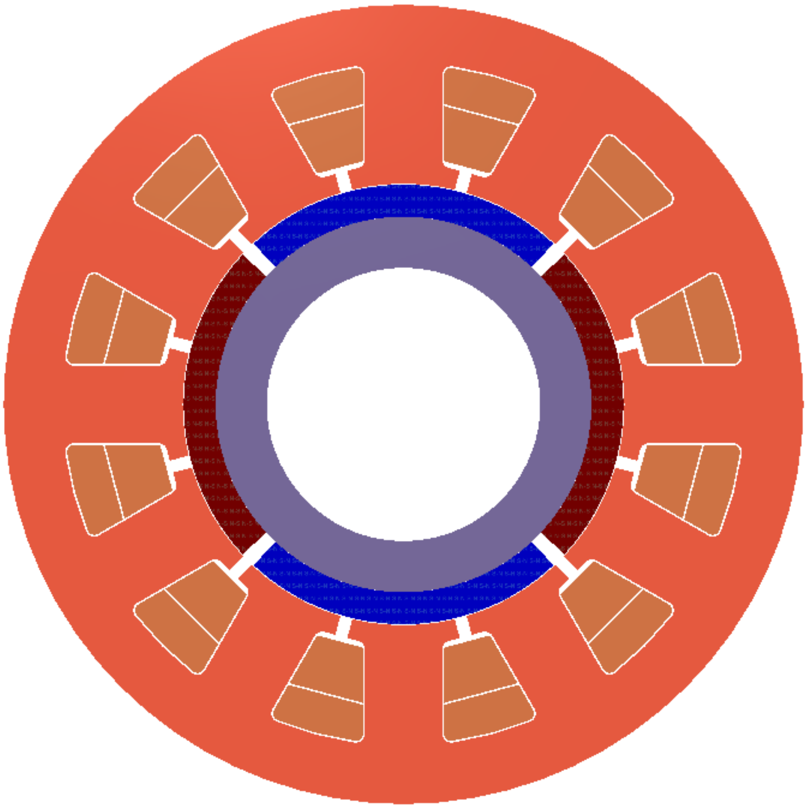


Figure 4.8: Improved Design of 30 W , 50rpm motor model.

Flux Density And flux Function plot:

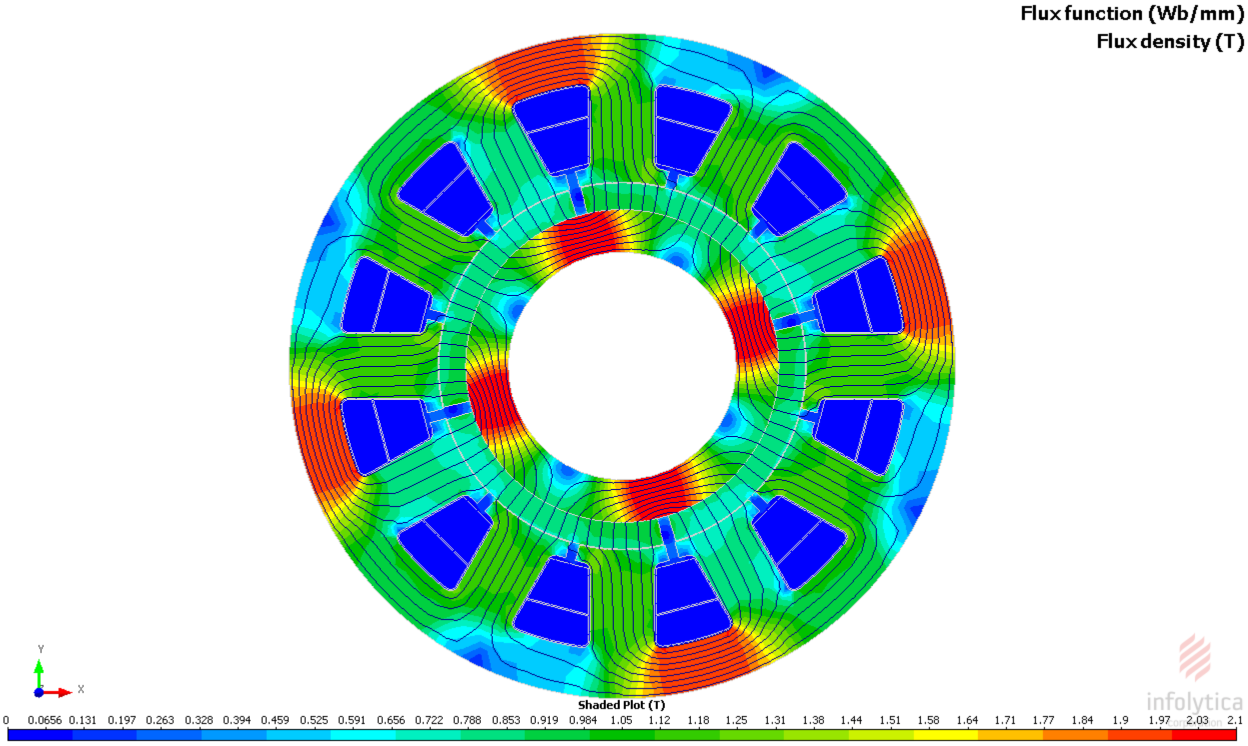


Figure 4.9: Instantaneous Field Plot for 30 W , 50rpm motor model.

Torque Curve:

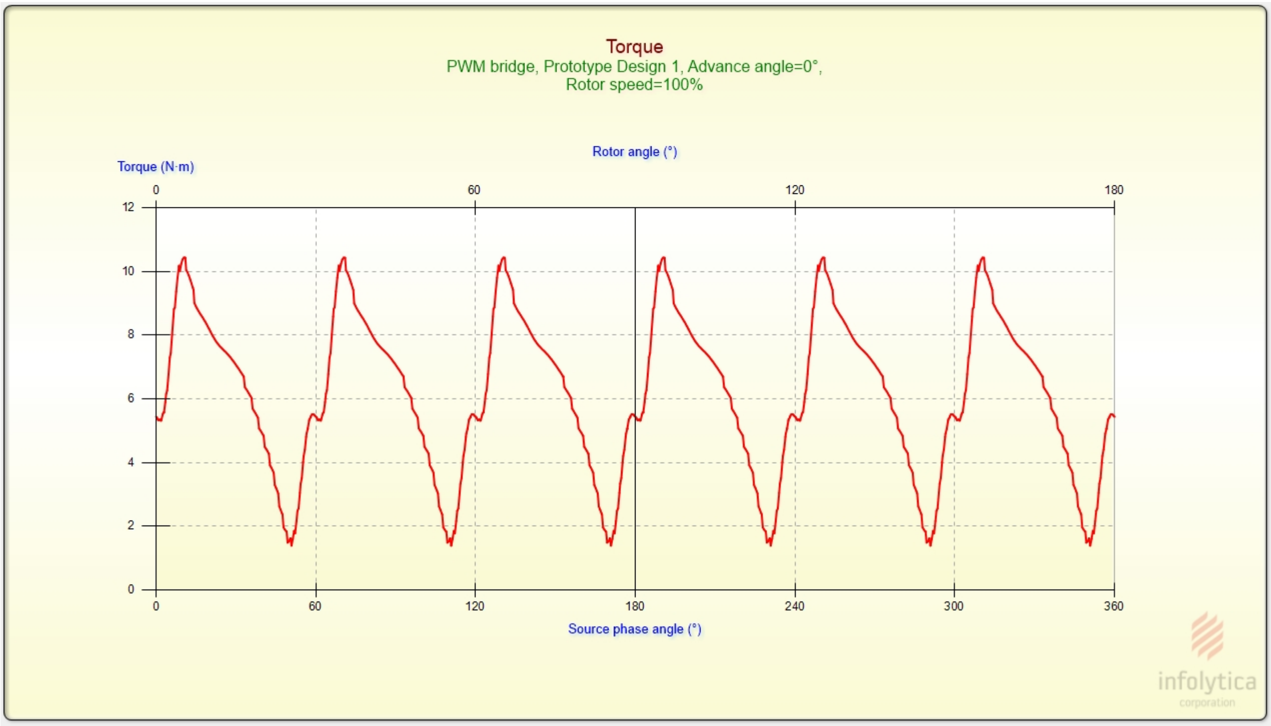


Figure 4.10: Torque profile of 30 W, 50rpm design.

Cogging Torque Curve:

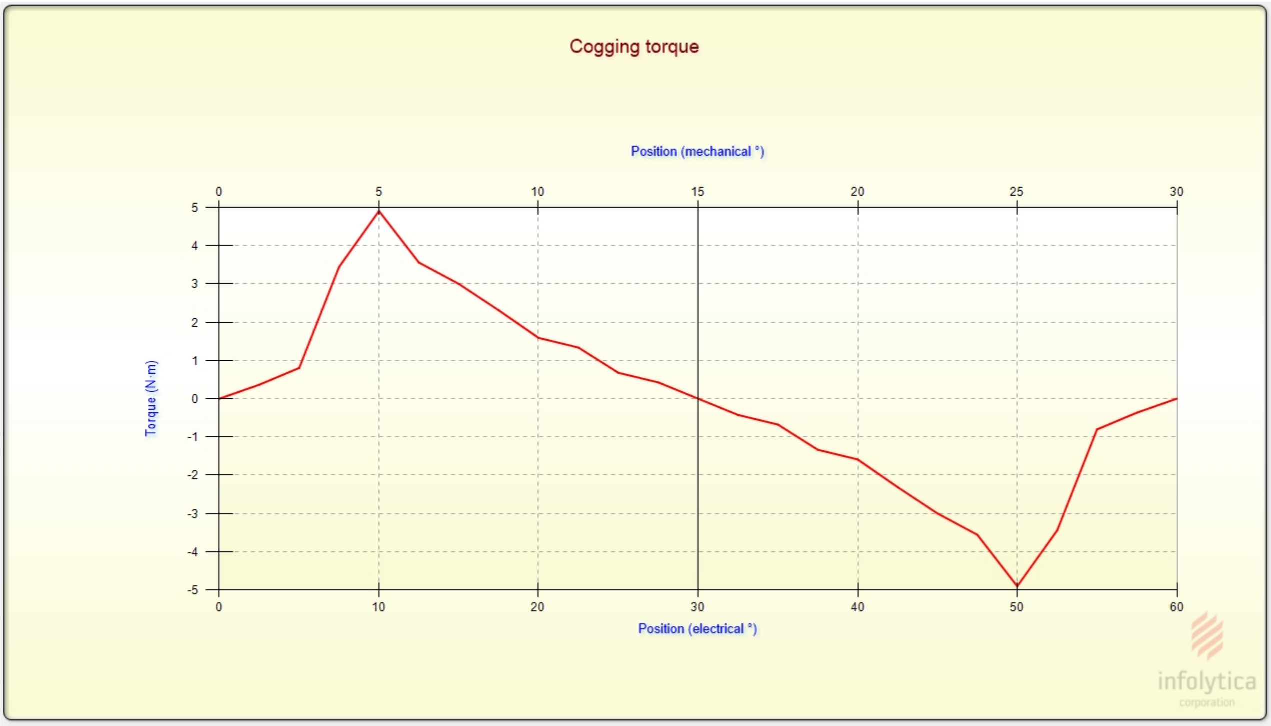


Figure 4.11: Cogging Torque profile of 30W, 50 rpm motor design.

Backemf Profile:

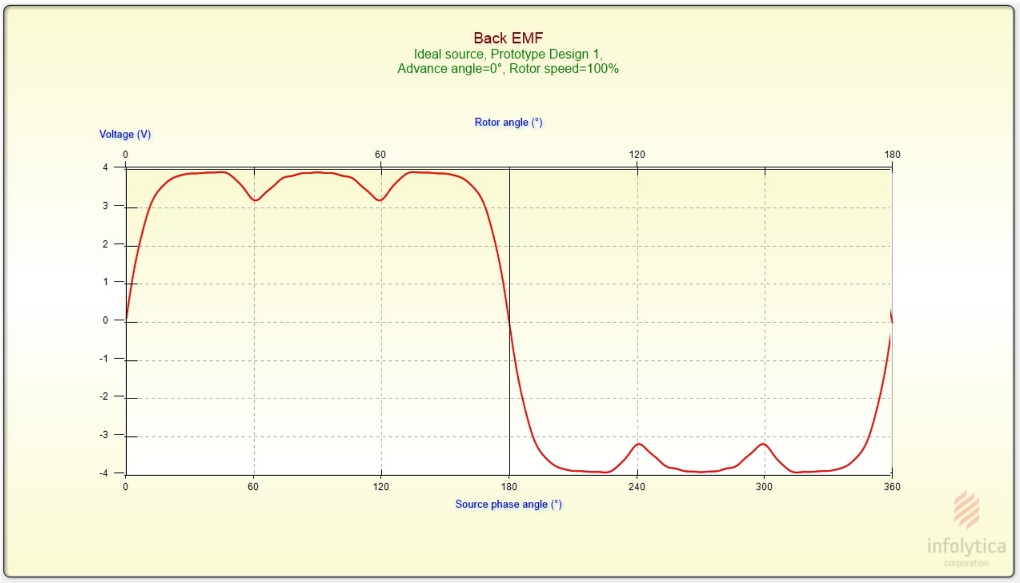


Figure 4.12: Backemf profile of 30 W, 50rpm motor design.

4.4 Performance Comparison

This section provides a performance comparison of two different models deigned to use M43 material and Hiperco50 material [ref erence model and enhanced model]. This segment provides a list of all three ratings that are used as follows

4.4.1 Weight Reduction Comparison of Initial and Improved Design:

Motor Parts	**Initial Design**	**Improved Design**
Rotor Core Weight(kg)	**1.47**	**1.12**
Rotor Magnet Weight(kg)	**0.671**	**0.421**
Stator Core Weight(kg)	**4.76**	**3.04**
Stator Winding Weight(kg)	**1.57**	**1.15**
Total Weight(kg)	**8.47**	**5.731**

4.4.2 Cost Comparison of Initial and Improved Design:

Motor Parts	Initial Material	Improved Material
Rotor Core Material	M-19 29 Ga	M-19 29 Ga
Rotor Magnet Material	NdFeB	NdFeB
Rotor Sleeve Material	304 Stainless Steel	304 Stainless Steel
Stator Core Material	M-19 29 Ga	M-43 24 Gage
Stator Winding Material	Copper	Copper

Motor Parts	Initial Material	Market Cost(Rs.)
Rotor Core Material	M-19 29 Ga	100/kg
Rotor Magnet Material	NdFeB	1500/kg
Rotor Sleeve Material	304 Stainless Steel	180/kg
Stator Core Material	M-19 29 Ga	100/kg
Stator Winding Material	Copper	408/kg
Stator Core(Improved) Material	M-43 24 Ga	75/kg

Motor Parts	Initial Cost	Improved Cost
Rotor Core Cost(Rs.)	147	122
Rotor Magnet Cost(Rs.)	1006	856
Stator Back Iron Cost(Rs.)	476	234
Stator Coil Cost(Rs.)	640	534
Total Cost(Rs.)	2269	1746

Chapter 5

Conclusion

5.1 Conclusion

In automotive applications electric motor compactness is highly desirable. PMBLDC Motor is designed for power window applications.Consider magnetic material is Neodymium-iron-boron(NdFeB) and core material is chosen M19-29Ga. Electromagnetic simulation has been conducted.According to design calculation results of electromagnetic simulation are closed to design requirement.

M19-G29 material is substituted with Hiperco and M43-29 Gage to increase the efficiency of the motor. By adjusting the material it affects the model in such a way that for 30 W, 50 rpm motor efficiency improves from shape of the motor as 60 % to 66 % for the size and similarly in the other case motor efficiency reduced from 60% to 56% and overall weight and cost of the motor also reduces respectively. .

5.2 Future Task

Reduction of Cost and Weight optimization of the permanent magnet will be achieved on the performance of different parameters.

Bibliography

[1] J.R. Hendersht Jr and TJE Miller,Design of Brushless Permanent Magnet Motors Oxford,U.K.: Clarendon, 1994.

[2] D. C. Hanselman, Brushless Permanent Magnet Design, McGraw Hill Inc. Publ, 1994.

[3] S Boopathi, K.Niruba,Advanced Power Window Motor using Permanent Magnet DC Motor.

[4] Divya V. Makwana1*, Prof. Mayalakshmi Pillai2, Prof. Yogesh Patel,Introduction to Permanent Magnet Brushless DC Motor (PMBLDC) Drives.

[5] Li S Sarlioglu B Jurkovic S Patel N Savagian P,"Comparative Analysis of Torque Compensation Control Algorithms of Interior Permanent Magnet Machines for Automotive Applications Considering the Effects of Temperature Variation", IEEE Transactions on Transportation Electrification,2017 vol: 3 (3) pp: 668-681

[6] Comanescu M Keyhani A Dai M "Design and analysis of 42-V permanent-magnet generator for automotive applications,IEEE Transactions on Energy Conversion", 2003 vol: 18 (1) pp: 107-112

[7] Stancu C Ward T Rahman K Dawsey R Savagian P, "Separately Excited Synchronous Motor With Rotary Transformer for Hybrid Vehicle Application", IEEE Transactions on Industry Applications,2018 vol: 54 (1) pp: 223-232

[8] Nagoya Kogyo Daigak"u,Electromagnetic Technology for Automotive Applications,2018 IEEE International Workshop on Electromagnetics": Applications and Student Innovation Competition : August 29-31, 2018, Nagoya, Aichi, Japan.

[9] Cui W Gong Y Xu M,”A permanent magnet brushless DC motor with bifilar winding for automotive engine cooling application”, IEEE Transactions on Magnetics, 2012 vol: 48 (11) pp: 3348-3351

[10] Hoon Park J Choi G Yoon T Bae Park J,A ”Sensorless Safety Power Window Control System in Automotive Application”,COEX 2008

[11] Bart L.J. Gysen, Jeroen L.G. Janssen, Johannes J.H. Paulides, Elena A. Lomonova, Design Aspects of an Active Electromagnetic Suspension System for Automotive Applications.

[12] Grazia Berardi, Michele Bonfante, Nicola Bianchi, Analysis Guideline to Determine Capabilities of IPM Motors for Automotive Application

[13] https://dir.indiamart.com/impcat/electrical-steel.html.

[14] goudsmitmagnets.com/magnets-assemblies/permanent-magnets/neodymium-magnets-rare-earth/neodymium-magnets-rare-earth.

[15] https://www.google.com/search?q=cost+of+304+stainless+steel+per+kgoq=cost+of+304aqs=c

[16] https://economictimes.indiatimes.com/commoditysummary/symbol-COPPER.cms.