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Optimization of Starter Motor for Automobile Applications

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Abstract

Normally, both brushed dc Motor and brushless dc motor are used as a starter motor in the automobile application. This paper presents the optimization methodology for brushed PM dc motors. In this brushed dc motor will be a four pole twenty-five slots based machine. This model analysis involves the more number of analytical calculations and computation for the selection of the best model, performance and excellent material characteristics. This method is considered with the existing commercial dc motors to meet the same performance after reduction of weight with change of some parameters; for cranes to lift the loads, various trucks, drill hand tool and automotive application likes car, bike. Optimised DC machine designs using Ferrite permanent magnets are proposed and provide important size and weight reductions without losing of its performance. The finalized model and the existing model was solved using the MAGNET Software by FEA (Finite Element Analysis) to see the basic performance such as flux density, speed, torque, output power of the existing model.

Keywords: *DC brush motor, four-pole, ferrite bonded PM magnet, FEA, volume reduction, weight reduction*

INTRODUCTION

DC Motor over AC Motor

The main objective on optimization of the dc motor will be give more advantages such as the usage of material will be less in manner, the total cost-wise it gets reduced of the motor and the total space used before will large in area and by making them to a maximum compact size, which will be increases the mileage of the vehicle. Brushed dc motors are highly used in the major applications ranging from toys to gear motors, mainly stands for automotive applications or power tools

[1]. The main advantage of dc motors over an ac motor is that they can operate at high speeds (up to 20,000 rpm), directly from a battery. They are inexpensive, easy to drive and are readily available in all sizes and shapes.

Electrical Machine Design Challenges

Ever since the earliest electrical machines were built in the 1800's, inventors and engineers have busied themselves improving the designs of electrical machines [2–5]. This work, which is concerned with the design of optimal electrical machines, is another drop in that ocean. It was undertaken with the renewable energy and transportation sectors and their challenges in mind, but just as a hammer can be used for many things this work can be just as applicable to various other electrical machines [6–10]. The following paragraphs, the design challenges of some modern electrical machines will be discussed [11- 16]. Many applications, specifically many renewable energy applications require special machines that are well adapted to alternative forms of mechanical power. Some proposed wave energy systems, for example, require linear machines operating at very slow speeds. These typically have a low power density and the forces involved are very large. Direct drive machines have also become popular in wind turbines, eliminating the need for a gearbox a component that typically requires regular maintenance [12]. These machines also operate at relatively low speeds and the mechanical input power can be fluctuating in nature. Stirling engine applications, on the other hand, require short stroke linear machines operating at a higher frequency, typically in the order of 50 Hz. These machines must also meet other constraints on the total translator mass and force over the range of the stroke. Electric vehicles hold the promise of cleaner, more efficient transportation and although electrical machines are not necessarily the most prominent impediment to the widespread use of these vehicles, they remain a critical component with strict design constraints. For example, the electrical machines used in the hub of a wheel have stringent volume constraints. Efficiency has always been an important consideration, and even more so in the present day where we as the human race are growing more aware of the negative impacts of some of our activities. Although, designing electrical machines for high efficiency has been quite possible for some time, the challenge lies in finding more cost effective ways of achieving this. The costs of electrical machines have a significant impact on the total cost of electricity because these machines are critical components in the electricity generation process [16]. Designing machines that are inexpensive can contribute towards making renewable energy generation financially more viable and reducing the negative impacts of our power systems. Even from this brief discussion, it is clear that there are many things to consider when designing electrical machines. In order to meet all the requirements on electrical machines, the ability to accurately model their performance is of vital importance. Better modelling can lead to better designs [5].

Working Principle of Starter Motor

When the start switch is closed, the coils in the solenoid are energized creating a magnetic field. The field pulls the plunger inward which causes the shift lever to push the drive assembly into mesh with the ring gear on the engine flywheel. The current passes through the field coil then through the brushes and to the armature. The current creates interacting magnetic fields around the field coil pole pieces and the armature laminations pack and causes the armature to turn the armature turns the drive pinion, which turns the ring gear thereby cranking the engine. When the engine starts, the start switch is released. This causes the magnetic field in the solenoid to collapse and a return spring forces the plunger outwards. This opens the contacts and then disengages. The drive assembly from the ring gear.

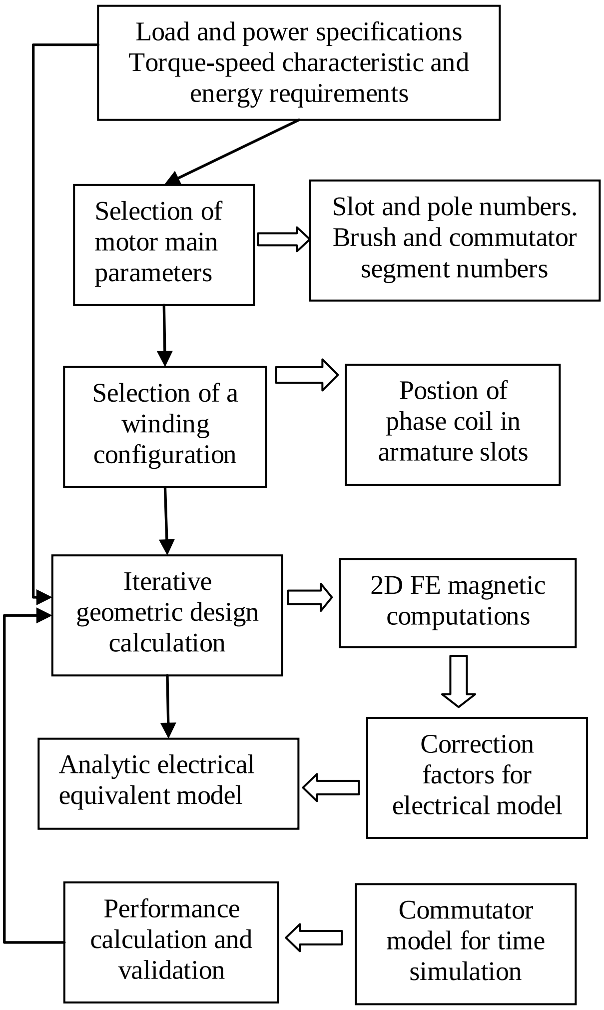
DESIGN METHODOLOGY

With the usage of formulations an analytical design model for dc brush motors has been developed and associated to an optimization procedure. The motor structure has cylindrical armature always and an external stator with permanent magnets [5, 8]. Figure 1 shows the DC motor Parts layout with 2 pole machine.

Fig. 1: *4P-25slot Conventional Dc Motor Layout.*

Table 1: *Dimensions of the Motor.*

PARAMETERS	**VALUES**
Outer Diameter of the Motor (mm)	70.9
Outer Diameter of the Magnet Poles (mm)	66.8
Number of Poles	4
Number of Slots	25
Types of Winding	40
Shaft Diameter (mm)	14
Core Length (mm)	30



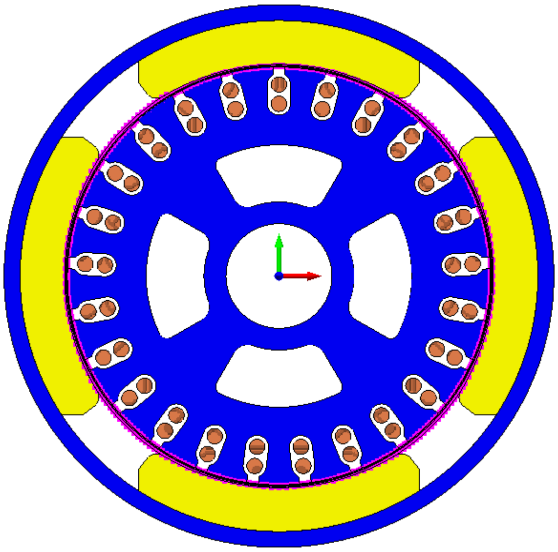


***Fig. 2:** Flow Chart of the Design Methodology.*

Magnet Software and Design Steps

MagNet is the 2D/3D simulation software for electromagnetic fields that rapidly model and predict the performance of any electromagnetic or electromechanical device [12]. It is solution approach is based on the highly accurate finite element method for simulating static, frequency dependent or time varying electromagnetic fields. MagNet includes many automated features which reduce the time to perform each design cycle. MagNet uses the finite element technique for an accurate and quick solution of Maxwell's equations [6]. Each module is tailored to simulate different types of electromagnetic fields and is available separately for both 2D and 3D designs.

Demagnetization

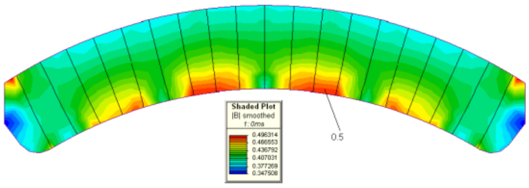


***Fig. 3:** Initial 2D Meshing.*

To Find Demagnetization, the temperature effect on permanent magnet is given by,

$$Br=Br20[1+\alpha B/100(Tpm-20)] \quad (1)$$

$$Hc=Hc20[1+\alpha H/100(Tpm-20)] \quad (2)$$

Where,

Br20 - Remanent Magnetic Flux density at 20˚c

Hc20 - Coercive Force at 20˚c

αB<0 - Temperature coefficient of Br. (Ferrite, Br = -0.2)

αH<0 - Temperature coefficient of Hc. (Hc =0.3)

Tpm - Permanent magnet temperature.

DESIGN EQUATIONS

The following are the list of formula that have been used in calculation of the various parameters which have been used to give as input using the simulation tool to get the predicated output parameter values.

Slot Fill Factor

Slot fill is usually given as a percentage figure that expresses the amount of wire in a slot in relation to the total slot area.

Slot fill factor = conductor area / slot area (3)

Slot area = (π* (toothtipdia^2 – rootdia^2) / 4 – tooth area) / No. of slots (4)

Conductor area = (π *(d^2)) / 4 (5)

Overhang Factor

Overhang factor to the amount of overhanging of the armature windings beyond the slots after the armature conductors. The overhang factor should be as less as possible so as to minimize leakage flux and circulating currents as both these leads to increased losses. Thickness of the chopper wire and the number of turns should be chosen accordingly

Overhang factor = 1+2*(1-e^ (-rotor core length)*(1-e^(3.4(rotor core length magnet length) / rotor OD) (6)

Yoke thickness = (Yoke OD – Yoke ID) / 2 (7)

Core area = ((Rotor rootdia – Shaft dia)*Rotor length) / 2 (8)

The Main parameters want to consider on optimisation of the Dc machine, the performance of the Speed, Torque and Gear ratio not to be change.

$$\text{Speed} = 2*\pi*\frac{\text{Speed}}{60} \qquad (9)$$

$$\text{Gross Torque} = \frac{\text{Output power gross}}{\text{speed}} \qquad (10)$$

After many trials have done the best performance model will be selected for optimization and analysis

FINITE ELEMENT ANALYSIS

The most popular technique currently available for the modelling of electrical machines is finite element analysis. This method allows many machine parameters, such as torque, power and efficiency to be calculated accurately through direct evaluation of the magnetic field in the domain of the machine and allows designs to be evaluated for many different criteria. In the finite element method of analysis, the model is divided into a mesh of elements. The field inside each element is represented by a polynomial with unknown coefficients [17, 18]. The finite element analysis is the solution of the set of equations for the unknown coefficients. The accuracy of the solution depends upon the nature of the field and the size of the mesh elements. In regions where the direction or magnitude of the field is changing rapidly, high accuracy requires small elements or high polynomial orders (or a combination of both). Magnets provide you with control over the size of the mesh elements. You can change the size of the elements for the entire model or only in areas of interest.

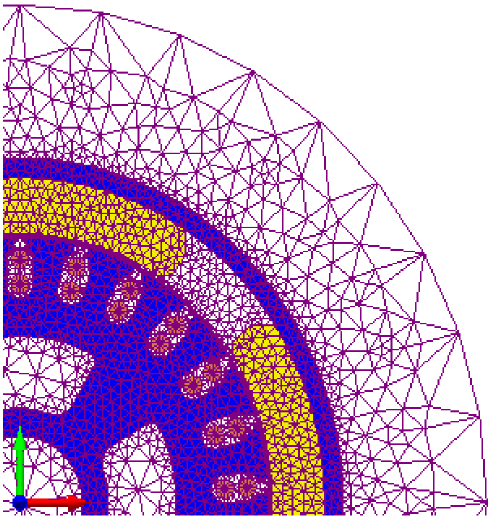


Fig. 4: *Initial 2D Meshing.*

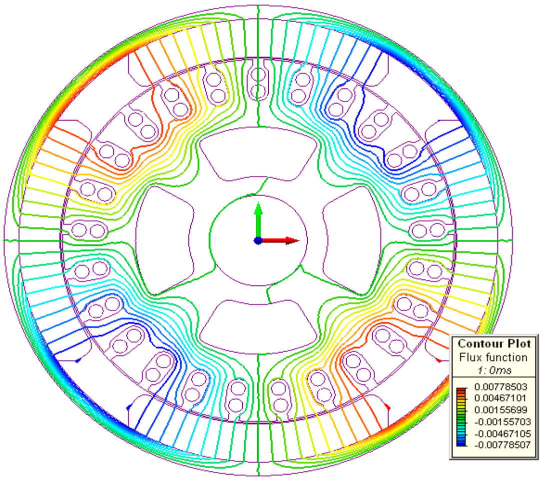


Fig. 5: *No load Flux Density Level.*

ANALYSIS RESULTS

Transient Method Solve

By using velocity driven, transient analysis step size can be applied for 1° mechanical shift for every time step for the given speed. For skewing the armature of magnet this analysis data will be useful. Analysis is faster than load driven as such no time for speed settlement. From the data driven the speed of machine was shown in the Figure.

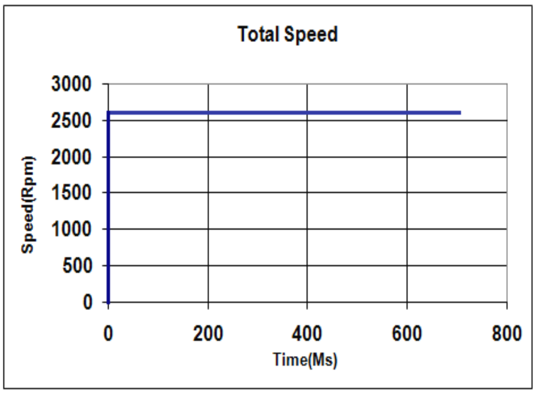


Fig. 6: *Speed Characteristics Curve for Brushed DC Motor.*

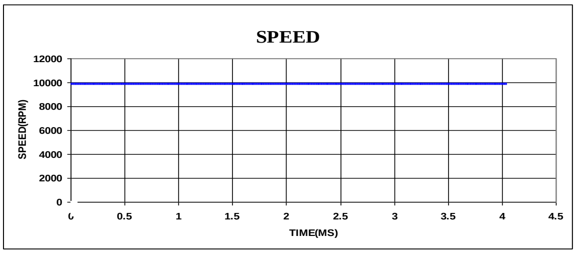


Fig. 7: *Speed Characteristics Curve for BLDC Motor.*

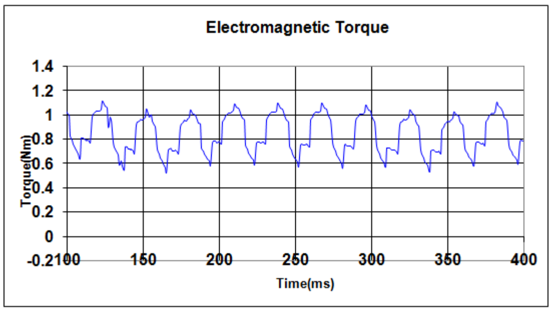


Fig. 8: *Electromagnetic Torque Characteristics for Brushed DC Motor.*

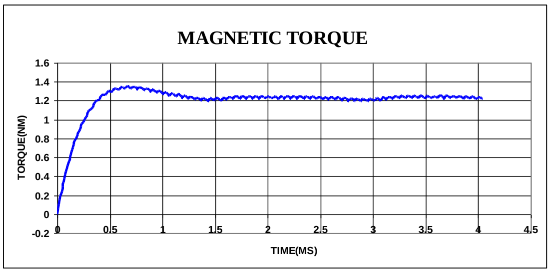


Fig. 9: *Electromagnetic Torque Characteristics for BLDC Motor.*

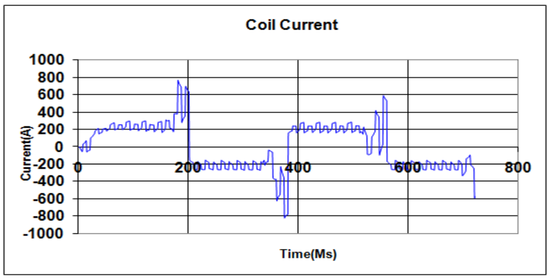


Fig. 10: *Coil Current Waveform Brushed DC Motor.*

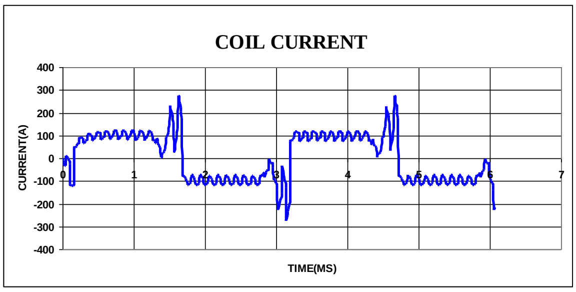


Fig. 11: *Coil Current Waveform BLDC Motor.*

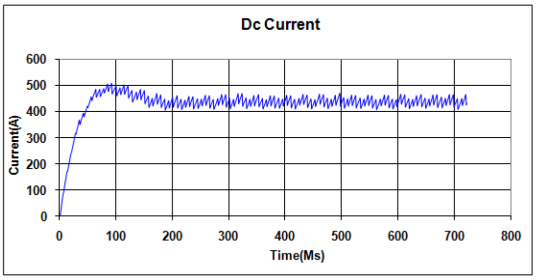


Fig. 12: *DC Current Characteristics for Brushed DC Motor.*

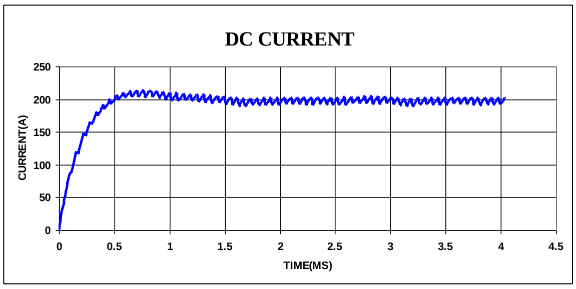


Fig. 13: *DC Current Characteristics for BLDC Motor.*

COST ESTIMATION

Cost Details		
Parameters	**Exist**	**New**
Yoke	18.66	16.26
Copper	63	61.5
Lamination	32.76	30.58
Magnet	27.15	23.7
Total Cost	141.57	132.04

CONCLUSION

In this research, DC permanent magnet motors have been analyzed via both static and transient methods. The time stepping Finite Element Method (FEM) has been used as a numerical method. The new designed which will be optimized for Brushed DC Motor (BDC) using permanent magnet as ferrite material. To meet the same performance of current and torque range as 200 RPM and 6.1 Nm, the motor get optimised and the weight reduces to nearly 100 g. From this it is observed and studied if we change the permanent magnetic material from ferrite to NdFeB material, we can achieve large weight reduction than this material.

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REFERENCES

1. B.Abdi, J.Milimonfared, J.S. Moghani. Simplified design, optimization and comparative study of SPM, BLDC and Halbach machines for microsatellite electro-mechanical batteries. *IEEE Transactions on Aerospace and Electronic Systems*. 2014; 51(1): 31-39p.
2. Bai Ying, Tao Guozheng, Yuan Minghai. Research on permanent magnet constant voltage device for vehicle. *International Conference on Measuring Technology and Mechatronics Automation*. 2010; 136–138p.
3. Bhim Singh, Jally Ravi. Design and analysis of a 3 kVA, 28 V permanent magnet burshless alternator for light combat aircraft. *IEEE*; 2006.
4. Franco Leonardi, Bogdan Ionescu. Advancements in tools and method for the design of permanent magnet integrated starter alternators. *IEEE*. 2005; 212–218p.
5. I.Boldea, S.A. Nasar. Permanent–magnet linear alternators part ii: design guidelines. *IEEE Transaction on Aerospace and Electronic Systems*. 1987; 23(1): 79–82p.
6. C. C. Hwang, S. B. John, S. S. Bor. The analysis and design of a NdFeB permanent-magnet spindle motor for CD-ROM drive. *IEEE Transaction on Energy Conversion*. 1999; 14(4): 1259–1264p.
7. David Brown, Bao-Min Ma, Zhongmin Chen. Developments in the processing and properties of NdFeb-type

permanent magnets. *Journal of Magnetism and Magnetic Materials*. 2002; 432–440p.

8. H. M. Cheshmehbeigi, E. Afjei. Design optimization of a homopolar salient-pole brushless dc machine: analysis, simulation and experimental tests. *IEEE Transaction on Energy Conversion*. 2013; 28(2): 289–297p.
9. J. Cros, G. C. R. Sincero, P. Viarouge. Design method for brush premanent magnet DC motor. *IEEE*. 2009; 1625–1632p.
10. Li Yu, Zhuoran Zhang, Zhihui Chen, yangguang Yangguang Yan. Analysis and verification of the doubly salient brushless dc generator for automobile auxiliary power unit application. *IEEE Transaction on Industrial Electronics*. 2014; 61(12): 6655–6663p.
11. Michael W. Degner, Richard Van Maaren, Azza Fahim, et al. A rotor lamination design for surface permanent magnet retention at high speeds. *IEEE Transactions on Industry Applications*. 1996; 32(2): 380–385p.
12. Mihai Comanescu, Ali Keyhani, Min Dai. Design and analysis of 42-V permanent–magnet generator for automotive applications. *IEEE Transaction on Energy Conversion*. 2003; 18(1): 107–112p.
13. N. Hamada, K. Noguchi, C. Mishima, et al. Development of anisotropic bonded magnet applied to 150^0 C use. *IEEE Transaction on Magnetic*. 2005; 41(10): 3847–3 849p.
14. Ping Zheng, Chengde Tong, Jingang Bai, et al. Electromagnetic design and control strategy of an axially magnetized permanent–magnet linear alternator for free–piston stirling engines. *IEEE Transaction on Industry Applications*. 2012; 48(6): 2230–2239p.
15. Reza Nasiri Zarandi, Mojtaba Mirsalim, Andrea Cavagnino. Analysis, optimization and prototyping of a brushless dc limited –angle torque–motor with segmented rotor pole tip structure. *IEEE Transaction on Industrial Electronics*. 2015; 62(8): 4985–4 993p.
16. R. N. Firdaus, M. Norhisam, N. Mariun, et al. Comparison of the torque characteristics of ferromagnetic rotor double stator brushless DC permanent magnet motor. *IEEE International Conference on Power and Energy*. 2012; 408–413p.
17. Shi Liwei, Zhang Xueyi. Modeling and control of vehicles. *Permanent Magnet Generating Set IEEE*. 2008; 1318–1323p.

18. Y. Hayashi, H. Mitarai, Y. Honkura. Development of DC brush motor with 50% weight and volume reduction using an Nd–Fe–B anisotropic bonded magnet. IEEE Transaction on Magnetic. 2003; 39(5): 2893–2895p.