Journal of Brilliant Engineering 3 (2022) 4658

Brilliant Engineering

journal home: www.acapublishing.com/journals/4/ben

Research Article

Investigation of the Effect of Design Parameters of Small Brushless DC Motors on Motor Performance by Finite Element Method

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Keywords

DC machine, Efficiency, FEM, ANSYS-RMxpert, Power.

Abstract

Direct Current (DC) motors are widely used in industrial applications. The limited use of brushed models in some areas has brought Brushless Direct Current Motors (BLDC) to the fore. The constant need for maintenance of brushed type motors creates a disadvantage in variable conditions and in areas that are used continuously. For this reason, brushless DC motors have a wide range of uses. Brushless DC motors stand out with their high-performance values. Brushless DC motors with outer rotor type are used in applications that require high torque and inertia. The fact that electrical machines have moving parts and the computational complexity created by these parts have led electrical machine designers to alternative ways such as software and simulation programs where the results can be predicted. In this paper, a Brusgless Permanent Magnet Direct Current motor (BLPMDC) was designed and analyzed. The obtained speed, efficiency, torque, and air gap flux distributions were examined and the results were compared with literature for the motor type. In this study, applications were made to examine the effects of design parameters such as rotor structure, rotor position, magnet arrangement and materials used in the structures on the efficiency and output power of the motor. Efficiency-speed and power-speed values were obtained for different structures and features of the engine. The results obtained are compared with each other and presented in the article in the form of graphs and tables.

1.Introduction

With the developing technology, the number of high-performance products that make human life easier is increasing day by day. Along with the increasing smart technology, integrated products arising from the machinery and electronics sector are also being introduced. One of them is brushless direct current (DC) motor. It provides many advantages such as high torque density, absence of brush losses, low moments of inertia, good speed control, low maintenance costs, quiet operation and high efficiency compared to brushed DC and stepper motors, which are other stakeholders in the sector, and are used in many application areas in the sector found. In addition, although there are disadvantages such as the complexity of the control circuits and their high costs, studies to reduce the cost in this direction continue.

Some of the usage areas of brushless DC motors with different power and dimensions can be counted as industrial, household appliances, office vehicles, automotive, transportation and transportation, defense systems, health, aviation, construction-building vehicles and renewable energy systems applications.

In the literature, it is seen that the studies on the subject are generally in the direction of the use of engines in engineering systems, control, design stages and production process. In a study, studies were carried out on the simulation of brushless DC motor using ANSYS Maxwell 3D program. In this study, the temporary and steady state behavior of four different types of motors that can be used for high-performance electric bicycles are examined and the performances of the motors are evaluated [1]. In a study on the design and prototype production of an outer rotor brushless synchronous electric motor for electric bicycles, prototype tests were carried out using the experimental setup and it was found that it largely overlaps with the simulation results [2]. There are also studies on the use of electric motors, engine design and analysis in electric vehicles. Electromechanical applications of fuel, suspension, steering and braking systems in automobiles have been investigated [3-5]. The application of a switchable magnetic field in brushless DC motors for electric vehicles has been investigated. In the study, the electric motor used in the vehicle of the university's electromobile team was taken as reference, and studies were carried out to improve the system performance in the ANSYS Maxwell environment [6]. The design and optimization method for axial flux brushless DC motors that can be used in electric vehicles have been studied [7]. Apart from automotive applications, the design and design constraints of small-sized brushless DC motors for use in cooling systems have been investigated [8]. The usage performance of bearingless brushless DC motors for small liquid pumps has been investigated. The analysis of the system in which the design was made was carried out with the finite element method and the usability of the targeted system was confirmed by experimental studies [9]. The effects of the slot structure of a brushless DC motor and the switching angle of a cylindrical single-phase brushless DC motor were investigated using the finite element method, and the relationship between torque, efficiency and power was investigated [10].

In general, these engines are tolerated at small and medium powers. It has also been used for higher powers in recent years [11-16]. These motors, which have a simple structure, have independent or integrated electronic commutation, produce high torque per ampere and do not change according to the operation, these motors have attracted motors to wide areas of use, including domestic and industrial applications pushes to produce designs [17-20]. One of the configurations is a slotted and slotless BLDC motor. A spotless BLDC is a motor that comes without a stator core.

In this study, the effect of design parameters of small diameter brushless DC motors on motor performance was investigated depending on the number of revolutions. Analyzes were made using the “RMxprt” engine pre-design module of the ANSYS Maxwell program, and the results were presented comparatively for each parameter. In this study, the effect of structural changes on the stator and rotor of the brushless DC motor on the motor output power and efficiency was investigated. The aim of this study is not to find the ideal engine structure, but to examine what kind of changes the structural changes of the engine cause on engine performance.

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Received 08 April 2022; Revised 16 May 2022; Accepted 20 May 2022

https://doi.org/10.36937/ben.2022.4658

2. Material and method

2.1. BLDC motor structure and working principle

Information about the structure, working principle, ANSYS Maxwell program and the preferred analysis method in the analysis section are presented.

Brushless DC motor generally consists of a stator and a rotor with permanent magnets, as seen in Figure 1. The stator is the stationary part of the brushless DC motor and the rotor is the part that rotates. It consists of a core and three-phase windings placed in cavities. The stator is usually made of siliceous sheets to minimize iron losses. There are many physical parameters of the stator and rotor part. The change of each of these parameters creates significant changes in engine performance. Brushless DC motors cannot be operated by connecting them directly to the power source like conventional brushed DC motors or asynchronous motors. For this, a driver system is needed as seen in Figure 1. Brushless DC motor works by triggering the stator phase windings of a DC power supply through a power electronic circuit under the control of a microcontroller. Permanent magnets generate rotor flux. Energized stator windings provide the rotational movement of the rotor by attracting the rotor magnets with the electromagnetic field they create. By energizing the stator phases in the appropriate order, the continuity of the rotating field is ensured. The operation of the motor is realized by following the rotating field by the rotor. Brushless DC motors can be used in application areas not only with the driver, but also with the reducer structure that will create a step according to the speed and torque value.

2.2. Motor design and Analyses Using ANSYS-Maxwell

Recently, electric motor design and development studies have gained importance as it takes place in many application areas. Electric motors are a system consisting of electrical, magnetic and mechanical subsystems. There are different methods such as magnetic circuit analysis and finite element analysis in examining the magnetic field distribution of an electromechanical system. If the geometric configuration is done properly, the finite element analysis gives very accurate results. The capacity and power of the computers used today also enable to obtain analysis results in a short time.

In order to obtain more understandable and faster results in engine design, many software packages are used today. By using these software, the parameters to be used in prototype production can be reached in a shorter time and unnecessary costs can be avoided. Engine design process; Determination of design requirements proceeds as analytical design and calculations, magnetic design and calculations, thermal design and analysis. In this process, the nominal and maximum power supply voltage range of the motor, motor torque, target efficiency, target weight and volume values are important.

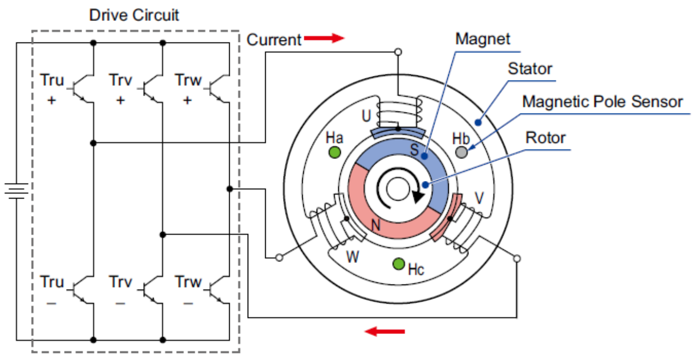

Figure 1. Basics BLDC motor

The basic equations describing an electromagnetic field are Maxwell's equations. The ANSYS Maxwell program also performs low-frequency electromagnetic circuit problems by solving Maxwell's equations using the finite element method according to the appropriate boundary conditions and user-specified requirements. In this study, many parameters affecting engine performance were examined in the engine preliminary design module (RMxprt) of ANSYS Maxwell program and their effects on engine performance were evaluated. The structure of the engine used is presented in Figure 2.

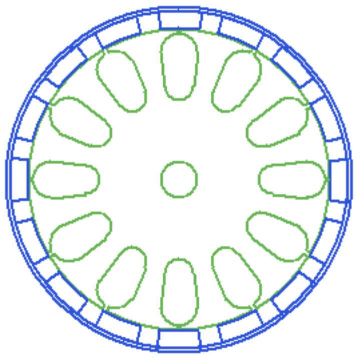

Figure 2. The structure of the engine used

In the paper, firstly, the typical brushless outer brushless DC motor structure, which is in the library of the "RMxprt" module of the ANSYS Maxwell program, was chosen to examine the effect of the structural parameter changes in the stator and rotor of the motor on the efficiency and output power in a certain speed range. This type of motor structure has been preferred because it is widely used in the industry due to its features such as ease of control and cooling. While entering the parameter information of the motor, taking into account the industrial applications where small motors are used, the stator outer and inner diameter, power, voltage, speed and operating temperature parameter values that can be accepted in these sectors are given as input. By analyzing the engine values given in Table 1, the efficiency-speed and engine output power-speed graphs of the reference engine in Figure 3 and Figure 4 were obtained.

Table 1. Parameters of the machine used in the analysis

Name	Value
Load Type	Const Power
Rated Output Power	15W
Rated Voltage	134V
Rated Speed	187.5rpm
Operating Temperature	75 °C
Machine Type	Brushless Permanent-Magnet DC Motor
Number of Poles	16
Frictional Loss	0.5 W
Windage Loss	0.75 W
Circuit Type	Y3
Stator Outer Diameter	134mm
Stator Inner Diameter	17mm
Stator Length	8mm
Stator Stacking Factor	0.95
Number of Slots	12
Outer diameter of the rotor core	154mm
Inner diameter of the rotor core	134.5mm
Length of the rotor core	26mm
Magnet Thickness	8mm

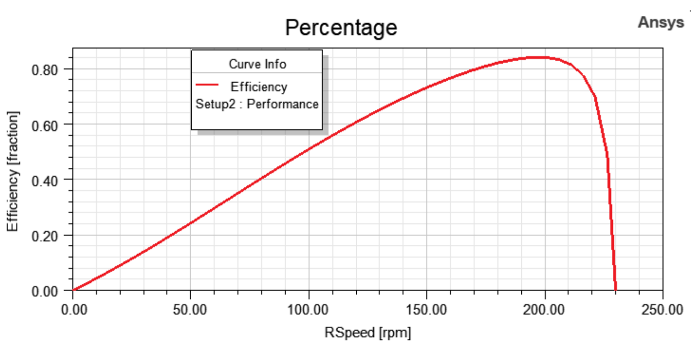

Figure 3. Efficiency-Speed graph

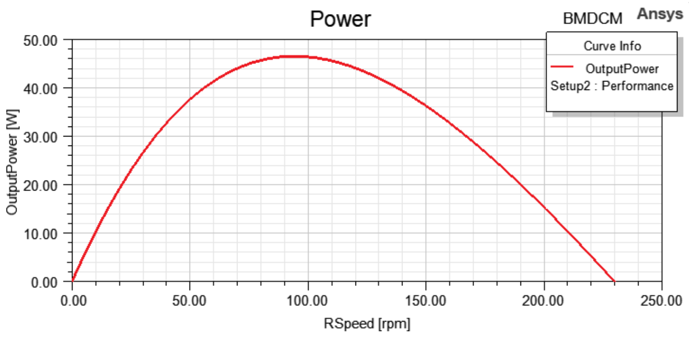

Figure 4. Power-Speed graph

3. Results and Discussion

In this section, the results of the analysis in which the parameter changes made on the designed brushless motor structure are examined. The effects of the sheet lamination package length, slot type, rotor magnet material, magnet arrangement and rotor position change of the motor on the system performance were examined, respectively, and the effects of the parameters on the efficiency and output power in a certain speed range were examined by comparing the performance graphics.

3.1. Analyzes of Motor Stator Using ANSYS-RMxpert

In this section, the analysis results obtained by increasing and decreasing the length of the motor stator and rotor lamination sheet package by 4 mm compared to the reference motor are given. When the efficiency-speed graph in Figure 5 is examined, it is seen that while the efficiency of the motor with increased lamination sheet package length is higher than the reference motor, it decreases rapidly after 95 rpm. On the other hand, it was observed that the engine efficiency increased slightly after 100 rpm in the engine whose lamination sheet package length was reduced. In the output power-speed graph given in Figure 6, it is seen that it provides the best motor output power when the sheet lamination package length is reduced. While the power values remain close up to the speed value of 100 rpm, the power output seems to be better when the sheet lamination package length is reduced in the case of operating at higher speeds than this value.

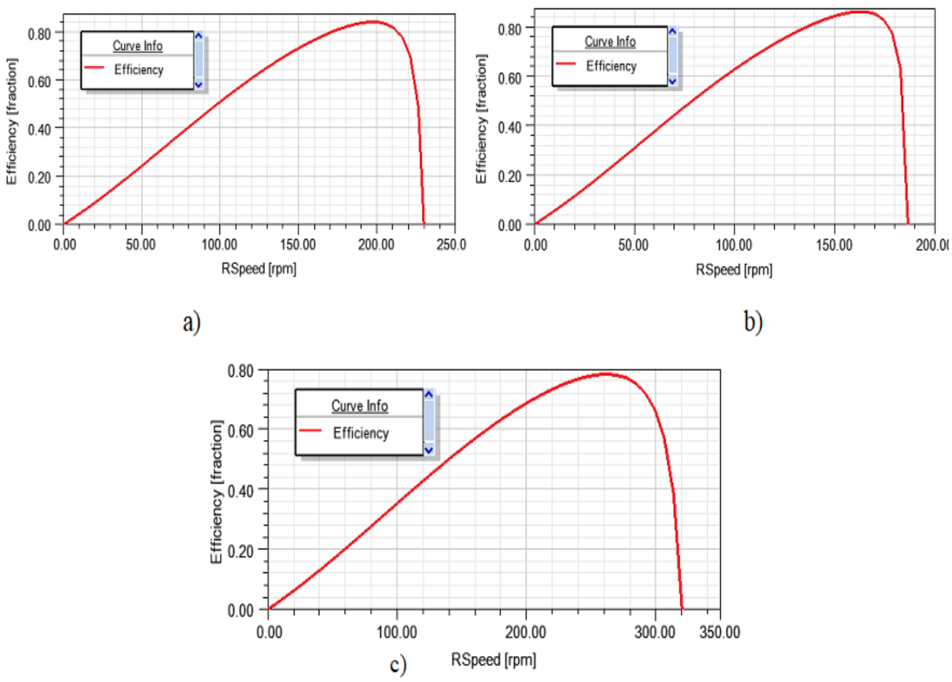

Figure 5. a) Efficiency-speed graph of the first designed engine, b) Efficiency-speed graph of the increased size of the engine, c) Efficiency-speed graph of the reduced size engine

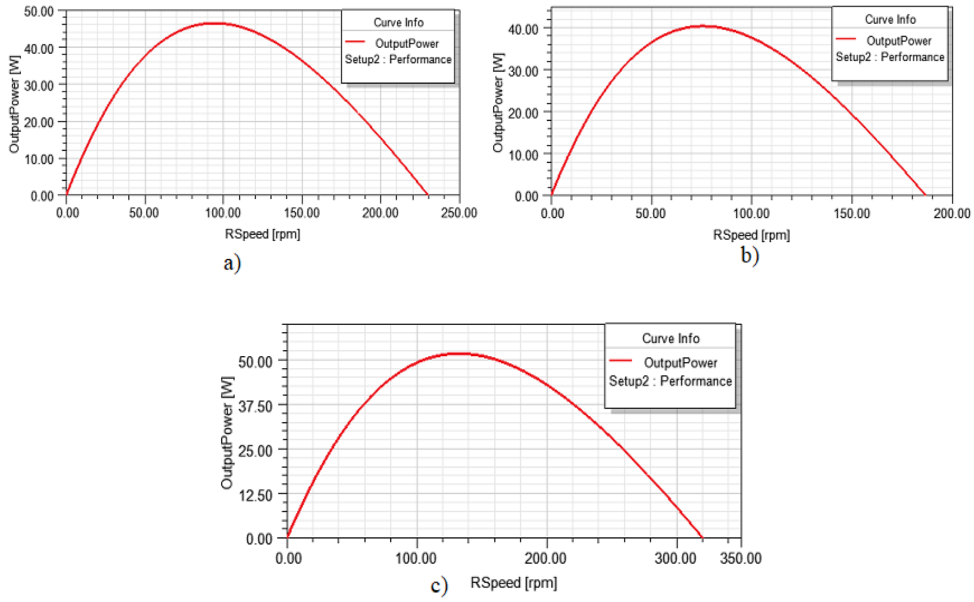

Figure 6. a) Output power-speed graph of the first designed engine, b) Output power -speed graph of the increased size of the engine, c) Output power -speed graph of the reduced size engine

3.2. Analyzes of Motor Rotor Using ANSYS-Rmexpert

In this section, analyzes were made with the XG196/96 permanent magnet material used in the reference motor and the Neodymium, Samarium and Ceramic permanent magnet materials that can be used in brushless DC motors. Considering the energy density, they can be listed as M127-027S, XG196/96, NdFe35 and M50A-30 magnets. Efficiency-speed and output power-speed values obtained with different magnet properties are given in Table 2.

Table 2. Efficiency-speed values obtained with different magnet properties.

Magnet type	Efficiency (%)	Speed (rpm)
M125-027S	80.2	155.6
X196/196	82.1	155.6
NdFe35	83.9	155.6

3.3. Magnet Array Variation

The effect of the arrangement of the permanent magnets on the rotor on the performance is examined with three different arrangement structures. These are the surface magnet type, channel type and inner type magnet arrays used. Permanent magnet material of the reference motor was used for all three types as permanent magnet material. Among these arrays, channel and inner type magnet arrays have manufacturing difficulties according to the rotor array of the motor with the reference name.

When the analysis results are examined, it is seen from Table 3 that the motor efficiency is lower in the channel and inner type magnet arrays than in the surface type array. It can be said that the most ideal magnet arrangement in terms of both ease of manufacture and performance features is the magnet arrangement with surface magnets.

Table 3. Efficiency-speed values obtained with different magnet array.

Magnet Array	Efficiency (%)	Speed (rpm)
Inner magnet	80.4	260.3
Surface magnet	82.1	194.7
Channel magnet	79.2	155.6

3.4 Change of Rotor Position

Rotor position in motors can be named as inner and outer rotor. The amount of air gap between the stator grooves varies according to the outer rotor and inner rotor design. The designed engine has an internal rotor engine structure in its initial state. In this part, only the magnet rotor structure is positioned externally, using stator dimensions with the same diameters. From the efficiency-speed and power-speed graph given in Figure 7, it has been observed that the efficiency of the inner rotor structure is higher than that of the outer rotor motor.

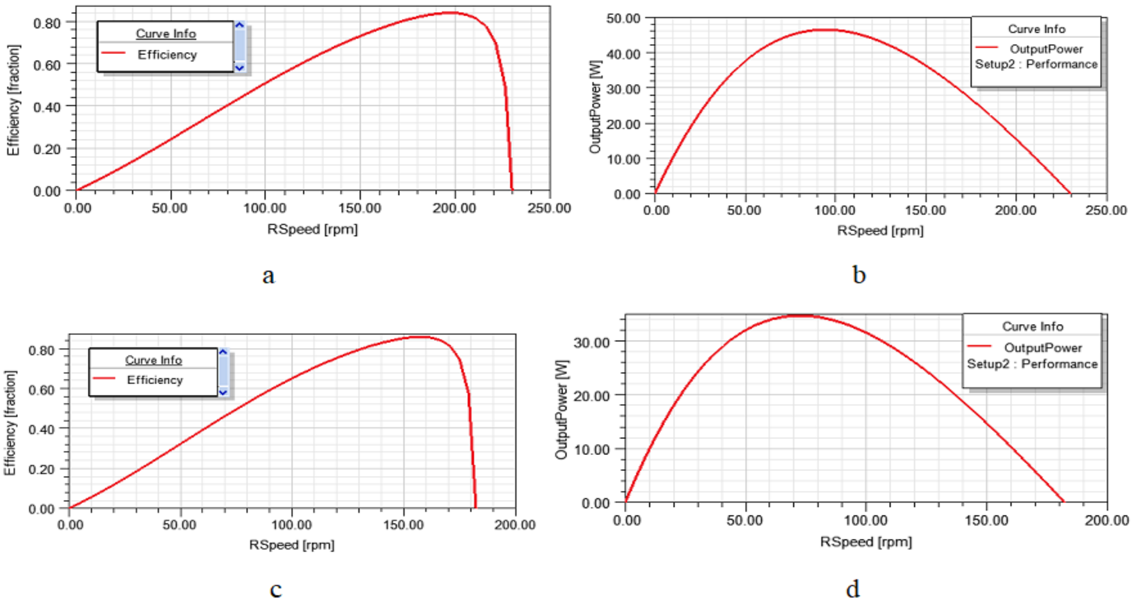

Figure 7. a) Efficiency-speed of inner rotor motor, b) Outpupower-speed of inner rotor motor, c) Efficiency-speed of outer rotor motor, d) Outpupower-speed of outer rotor motor,

According to the usage areas in the industry, the number of revolutions at which the motors will operate, the desired efficiency and output power may change. It is necessary to make structural changes that will bring the wishes to the fore in the designs to be made by taking into account the user's requests. From the comparison charts presented above, when the analysis results are evaluated in terms of efficiency under the operating conditions where the engine with the reference name is at its highest efficiency under full load; It can be seen that the correct selection of the stator slot type and sheet lamination length is effective in the stator part, and that the permanent magnet arrangement should be made appropriately in the rotor part. When the power outputs obtained at the maximum number of the same structure, where the highest power output is taken, are examined, it is seen that the slot type, sheet lamination length and rotor magnet arrangement should be done correctly. When the internal rotor structure was evaluated in terms of efficiency and power, it gave better results in terms of performance.

4. Conclusions and Recommendations

In this paper, a small size brushless DC motor that can be used in industrial applications was used and the effects of structural changes in the stator and rotor of this motor on the output power and efficiency of the motor were investigated in the defined speed range. Here, the effects of many different structural changes that will affect the system performance are examined collectively.

When the analysis results were examined, it was seen that the surface magnet motor was more suitable in terms of power and efficiency. It has been observed that the performance varies depending on the speed value when the length of the lamination sheet package and the use of different magnet materials in the rotor are used. It has been observed that the inner rotor motor works more efficiently at all revolutions even if the rotor position is inside or outside, and it has been observed that the outer rotor design provides more output power in the region close to its maximum speed in terms of power. It has been observed that the performance results change depending on the speed value in increasing the length of the lamination sheet package, the outer rotor design and the use of different magnet materials. Another parameter that shows a different character after a certain point according to the speed value is the magnet material. It has been observed that the materials are not very different from each other in terms of characteristics.

Acknowledgement

This study was supported by Dicle University BAP unit with project number SILVAN-MYO-22001. Thanks for your contribution.

Declaration of Conflict of Interest

The author declares that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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How to Cite This Article

Özüpak, Y., Investigation of the Effect of Design Parameters of Small Brushless DC Motors on Motor Performance by Finite Element Method, Brilliant Engineering, 3(2022), 4658.
https://doi.org/10.36937/ben.2022. 4658