Improve the efficiency of Brushless Permanent Magnet DC motor by ANSYS –MAXWELL 3D/ 2D

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Review of Brushless Permanent - Magnet DC Motors,
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Abstract

Brushless DC motors (BLDC) have received a lot of attention in the past decade from many sectors. Compared to other machines with equivalent power outputs, it is exceptionally light-weight and reliable, making it ideal for equipment that operates at high speeds. It is necessary to follow a process of design that is based on the fundamental concepts of electromagnetism is a fundamental need, even when machine design procedures are available as a collection of many distinct sources. The objective of this research is a DC motor (BLPMDC) with internal permanent magnets. Once the static and rotating materials are identified, the realistic size and power output can be approximated based on this information, Cogging torque causes vibration and noise in BLDC motors. It's caused by rotor magnets interacting with stator teeth. This research examines reducing cogging torque in brushless motors by altering slot depth. Cogging torque decrease is analyzed using FEM. Increasing stator slot depth reduces cogging torque in 1000 W/60V/3000RPM BLDC motors. These findings verify the FE approach.in Maxwell's RMXPRT (36-hole, 10-pole) module based on 2D and 3D Maxwell's equations and then converting the internal program to binary 3D and 2D from RMXPRT and know the good efficiency of the motor.

Keywords: *Mesh operations, efficiency, Brushless Permanent Magnet DC motor, Ansys Maxwell, Cogging torque, stator slot depth, finite element method (FEM).*

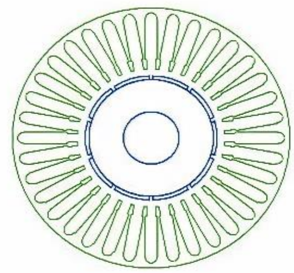
1. INTRODUCTION

This is a result of the increasing need and demand for electric drivetrain units in automobiles, which has led to a large growth in electric motor research. New ideas and advances in motor design have been spurred by a desire to outperform the performance of current motors[1]. Even with such remarkable improvements in the operation and efficiency of the motors, industrial and automotive applications still have a lot of opportunity for development. Using electrical modeling[2].I was able to accurately anticipate the torque and power output that can be expected from the existing BLDC motor arrangement by considering design modifications Since brushless permanent magnet type motors are unaffected by power struggles between car firms, they were an obvious choice as a study topic over induction motors[3]. The only probable explanation for this fact is the benefits it offers over the former. An efficient, compact and light-weight motor type is used. Slots stamped inside the rotor's laminations hold the permanently inserted inner magnets[4]. Because of its superior anti-demagnetization properties and higher strength and durability, the inside permanent magnet configuration is preferred for use in research over the surface permanent magnet motor As a result, the chance of magnets being torn off by centrifugal forces is reduced when the magnets are buried in slots in the rotor's core[5]. Although the present automobile industry depends heavily on BLDC and PMSM type motors owing to their high power and torque density, I think a more dependable and efficient electric machine may be created via extensive study on a redesigned structure that incorporates BLDC and IPM type motors[6]. In this study, a variety of performance criteria will be linked to the varied operating situations in order to authenticate the task. In addition, an electrical FEA simulation is started to assess the cogging torque in the motors and a parametric analysis is performed to compare the characteristic curves with variations in parameters[7]. The goal is to determine the optimal set of motor settings and then combine those findings[8].

2. Brushless Permanent Magnet DC motor

One of the most common DC motor types is the brushless DC motor, which is also known as a BLDC motor or BL motor. The synchronous motor's speed and torque are controlled by pulses of current sent by the controller to the motor windings[9]. These motors have a wide speed range and good efficiency in providing a considerable amount of torque. Permanent magnets surrounding a fixed armature in brushless motors solve the challenge of connecting the armature to the current. Electronic transportation offers a wide range of options and a high degree of customization. They are renowned for their smooth functioning and ability to maintain torque when stationary[10].

Figure 1. Cross-section views of BLDC[16].



Prior to discussing brushless DC motors, it is important to understand how a brushed DC motor works. A spinning armature that incorporates an electromagnet is included inside the permanent magnets of brushed motors. In order to spin the armature, these electromagnets generate a magnetic field when the power is turned on To maintain the armature rotating, the brushes adjust the pole's polarity. In both brushed and brushless DC motors, internal shaft position feedback plays a key role in the motor's overall performance. The rotor and stator are the only two constituent elements of a brushless DC motor. With regard to rotor and stator, they're the two parts that make up a complete machine: Electromagnets are connected to the rotor by permanent magnets, which move them to the stator. BLDC To spin the shaft, electromagnets are activated by high power transistors. The controller uses a solid-state circuit to distribute electricity. The rotor and stator are the only two constituent elements of a brushless DC motor. With regard to rotor and stator, they're the two parts that make up a complete machine: Electromagnets are connected to the rotor by permanent magnets, which move them to the stator. BLDC To spin the shaft, electromagnets are activated by high power transistors. The controller uses a solid-state circuit to distribute electricityThe rotor and stator are the only two constituent elements of a brushless DC motor. With regard to rotor and stator, they're the two parts that make up a complete machine: Electromagnets are connected to the rotor by permanent magnets, which move them to the stator. BLDC To spin the shaft[11].

3. Standard electromagnetism mathematical formulas and notations

Numbers of quantities are used in magnetic fields. They're all connected in some way. There are many similarities between magnetic flux (ø) and electric current (I) in a magnetic field. Magnetic field density (B) is inversely proportional to the flux (F)[2].

$$\mathbf{Ø = B.A} \tag{1}$$

Here, A is the magnetic flux path area. weber is the unit of magnetic flux density, and weber/m2 is the unit of magnetic field density.

Magneto-motive force (F) and path reluctance (R) may be used to determine magnetic flux.

$$\mathbf{F = NI} \tag{2}$$

I = current flowing through the coil, N = coil's number of turns. Then

$$\mathbf{Ø = \frac{F}{R}} \tag{3}$$

Equation (2) may be used to represent equation (3).

$$\mathbf{Ø = \frac{NI}{R}} \tag{4}$$

There are three factors that determine the magnetic path's reluctance: length, permeability, and area.

$$R = \frac{l}{\mu A} \tag{5}$$

A magnetic circuit's magneto-motive force (F) is analogous to an electric circuit's electromotive force (E). The density of magnetic fields (B) is comparable to the density of electric fields (D). It is one of the simplest and most beautiful ways to illustrate the foundations electrical and magnetic properties. Maxwell's equations may be used to construct most of the working relationships in an electromagnetic field that is either static or time-varying. Maxwell's equations differential for time variable situation is provided below in the differential form.

Gauss' Electricity Law

$$\nabla.\ \mathbf{D} = \dot{\rho} \tag{6}$$

Magnetic Gauss's Law

$$\nabla.\ \mathbf{B} = 0 \tag{7}$$

"Faraday's Induction Law"

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial} \tag{8}$$

The Amperes Law

$$\nabla \times \mathbf{H} = \mathbf{J} + \partial \mathbf{D}/\partial \mathbf{t} \tag{9}$$

$$\mathbf{D} = \varepsilon 0\mathbf{E} + \mathbf{P} = \varepsilon 0\mathbf{E} \tag{10}$$

$$B = \mu 0\ (H + M) = \mu 0H \tag{11}$$

E = Electric field, ṕ = Charge density, B = Magnetic field density, ε0 = Permittivity, J = current density, D =Electric displacement field, μ0 = Permeability, H = Magnetic field strength, M =Magnetization, P =Polarization.BLDC motor torque (T) is determined as determined by both the rotor's diameter (D) and its axial length (A) (L) An image of it is shown. by the following symbol

$$\mathbf{T = KD^2L} \tag{12}$$

Equation (12) shows that a motor's torque is mostly dependent on the rotor's diameter. Circumference area available for permanent magnets rises linearly with rotor diameter. It's possible, after all.

To put it another way: If the axial length is doubled at the same power, the torque will likewise double. The PM BLDC motor's cogging torque is the unintended torque generated by the rotor magnets' interactions with the machine's slots and poles. The PM BLDC motor's torque ripple is exacerbated by the cogging torque, which lowers the machine's overall torque. The torque caused by the cogging expression is provided by

$$T\ cog = -\tfrac{1}{2}\,\frac{\O g^{2dR}}{d\Theta} \qquad (13)$$

When the rotor is rotated by an angle, the reluctance of the air gap changes by dR/dϴ take into consideration that the majority strategies used to minimize The torque caused by the cogging diminish the effective back EMF and therefore mutual torque generation, which is crucial to remember.

4. MOTOR STRUCTURE DESIGN

4.1 Many machine-specific-, template-based interfaces for induction, synchronous and electrically and brush commutated machines are provided by RMxperttm. Templates like this one make it easy to input design parameters and analyze design tradeoffs early on in the development process. losses, flux in the air gap, and efficiency are all factors to consider when it comes to power. are just a few of the critical performance metrics that may be readily measured. To perform Finite Element Method and electromagnetic transient analysis, the model created in RMxpert may be readily converted to Maxwell project (2D/3D).[4]

4.2 STATOR CONSTRUCTION- provides stator statistics based on the parameters listed in Table 1 shows

Table 1. A SPECIFICATION OF MOTOR STRUCTURE. BASIC INFORMATION[12]

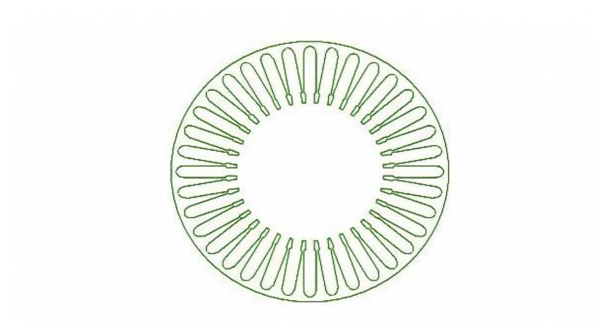
ELEMENTS	VALUE
Number of slots	36
Diameter outside (mm)	198
Diameter inside (mm)	105
stator core's length (mm)	77.16
Factor stacking	0.95
conductor for each slot	18

4.3 ANALYSIS STEPUP CONSTRUCTION

Table 2. Analytical setup for design[13]

ELEMENTS	VALUE
Power rating (w)	1000
Maximum voltage (volt)	60
maximum speed (rpm)	3000
Number of pole magnatic in rotor	10
Loss due to friction (W)	20
loss of windage (W)	10

Figure 2. depicts the stator's design[2]



4.4 THE PARAMETERS OF THE SLOT.

Figure 3. Dimensions of Slots[2]

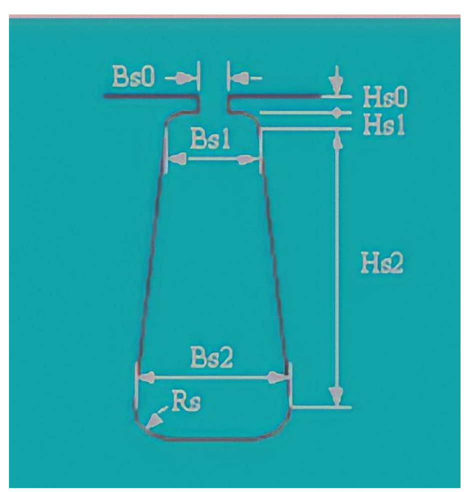


Table 3. show the slot's shape and measurements[2]

PARAMETER	VALUE
hs0[mm]	7
hs 1[mm]	0.9
hs 2]mm]	30
bs0[mm]	7
bs 1[mm]	9
bs 1[mm]	9
rs[mm]	5

4.5 CONSTRUCTION OF ROTORS.

It is a component that rotates inside the electric motor or generator's electromagnetic system. RMxprt provides a variety of rotor permanent magnet pole forms, but the one seen in Figure 4 is used.

Figure 4. depicts the rotor's design.[2]

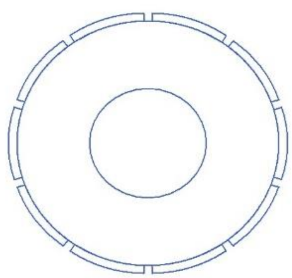


Table 4. lists the rotor's performance specifications.[7]

PARAMETER	VALUE
Smallest air gap (mm)	5
Diameter inside (mm)	40
Diameter outside (mm)	95
The rotor's length (mm)	42
Variety of steel	Steel_1008
Embrace	0.9
The magnet's thickness (mm)	3
Type of Magnet	Ndfe35
Magnetic Field Width (mm)	26.0128

Table 5. another critical component of a machine[14]

PARAMETER	VALUE
Density of Remaining Flux (Tesla)	1.1
Force Coercion (A/m)	883
Highest Energy Density (kj/m3)	230.45
Avg. Input current(A)	18.67
The RMS Armature current (A)	20.88
Armature Current Density(A_per_m^2)	1276600
Loss Due to Friction and Windage (W)	30.89
Iron Heart Losses (W)	0.0014
Loss of Copper from the Armature (W)	35.675
Loss of Transistor (W)	45.5
Loss of Diode (W)	8.25
Overall Loss (W)	120
Output Power (W)	1000
Input Power (W)	1120.36
Efficiency	89.259
Rated Speed (RPM)	3055
Rated Torque (N-m)	3.127
Maximum Output Power(W)	1859.47
Air Gap Ampere Turn(A.T)	1545
Magnet Ampere Turn(A.T)	-1559.9
Leakage Flux Factor	1

FIGURE 5. EFFICIENCY VS. SPEED[13]

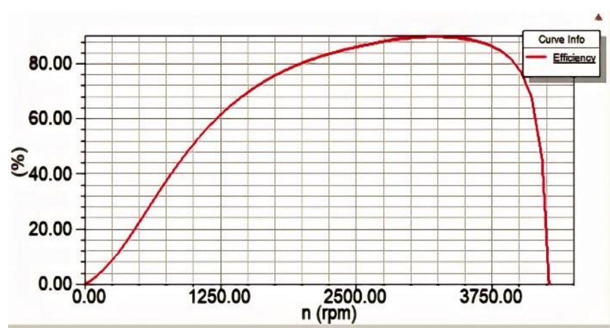


FIGURE 6. TORQUE VS SPEED[13]

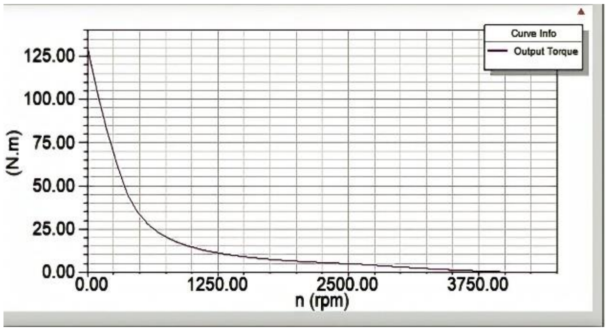


FIGURE 7. COGGING TORQUE VS ELECTRIC DEGREE [3]

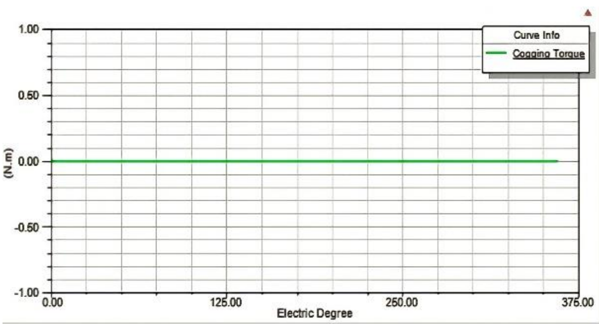


FIGURE 8. WINDING CURRENT UNDER LOAD VS ELECTRIC DEGREE[13]

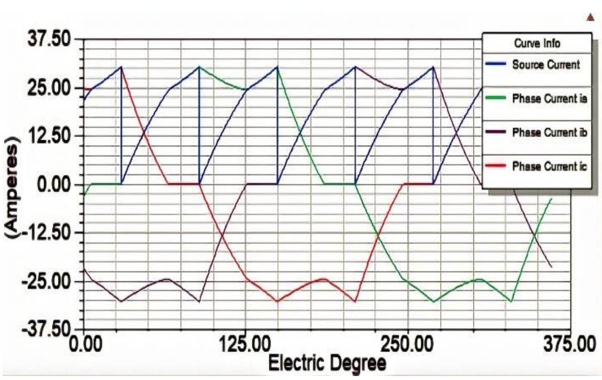
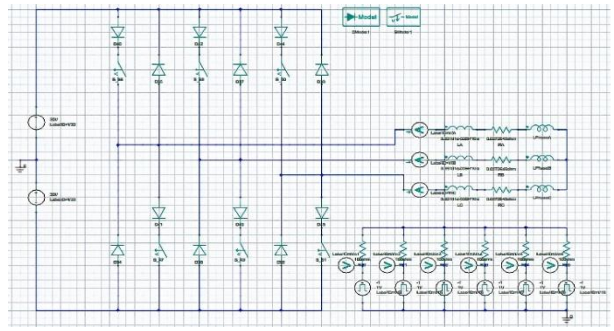


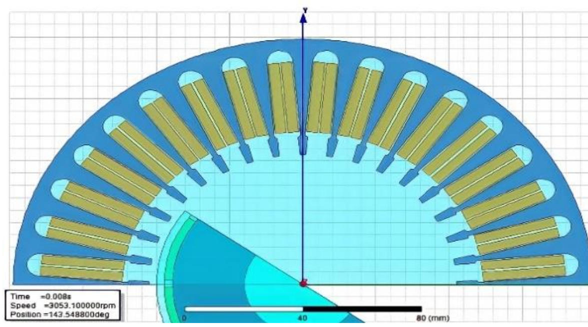
FIGURE 9. CONTROL CIRCUIT[4]



5. SIMULATION MAXWELL 2D.

Maxwell 2D is used to export motor designs created on RMxprt. FEA meshing may be generated with the help of this program [2]. Maxwell 2D is used for electromagnetic analysis. The Maxwell 2D motor is seen in the figure below. fig.10 [4]

Figure 10. Maxwell 2D motor[4]



Based on simulations, part of the analysis is done. Fig. 11 in Maxwell 2D illustrates the mesh creation at various points. rotating at the correct angle.

Figure 11. Maxwell 2D Mesh Formation[4]

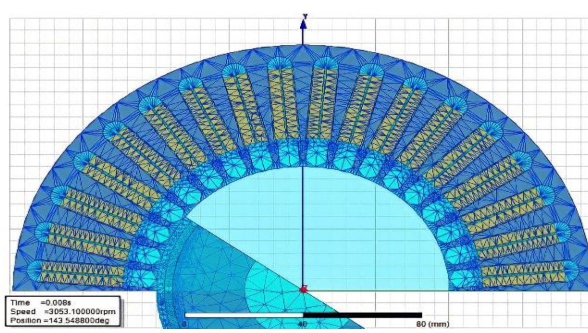


Figure 12. Density of the magnetic field at a certain rotor location[4]

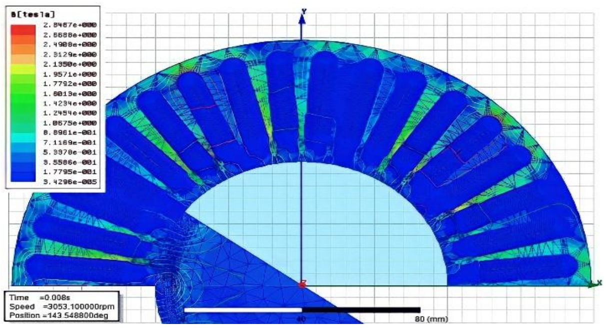


Figure 13. A given rotor position current density[4]

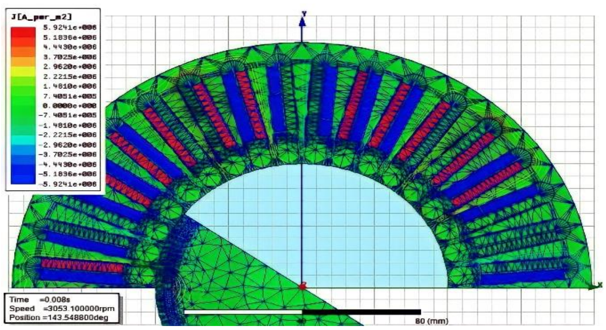
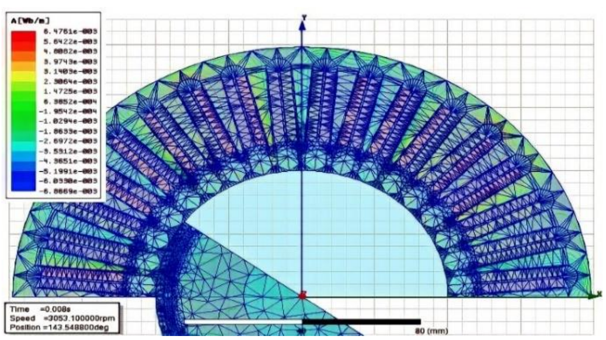


Figure 14. Maxwell Flux Lines Plot[4]



6. THE 3D SIMULATION OF MAXWELL.

A RMxprt-created motor model is imported into Maxwell 3D for rendering. FEA meshing may be generated with the help of this program. Maxwell 3D is used for electromagnetic analysis. The Maxwell 2D motor is seen in the figure below. in fig.15[15]

Figure 15. Maxwell 3D-modeled motor[15]

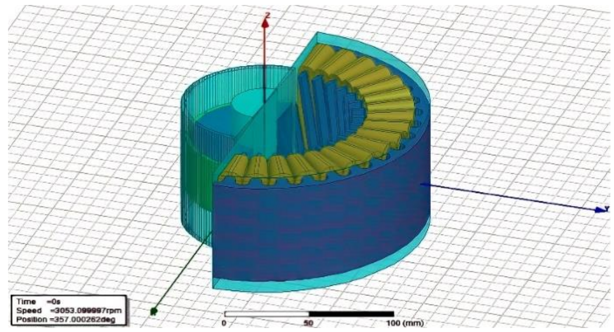


Figure 16. Maxwell 3D Mesh Formation[15]

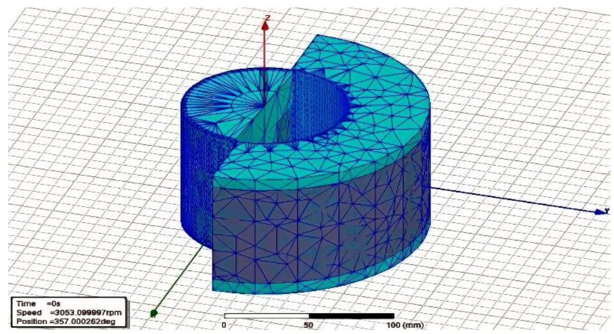


Figure 17. Density of the magnetic field at a certain rotor location[15]

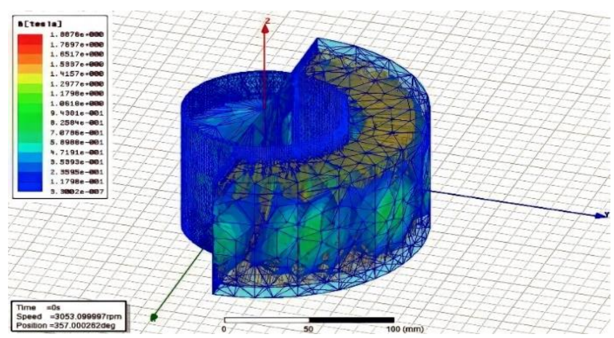


Figure 18. A given rotor position current density[15]

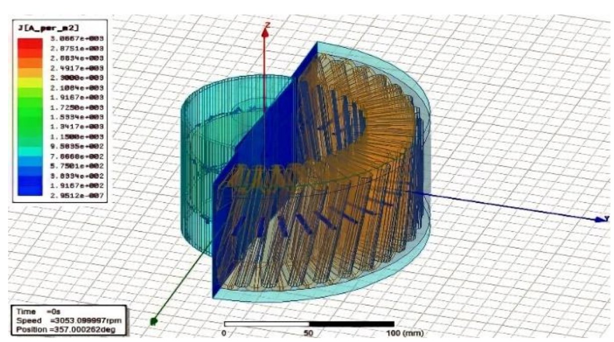
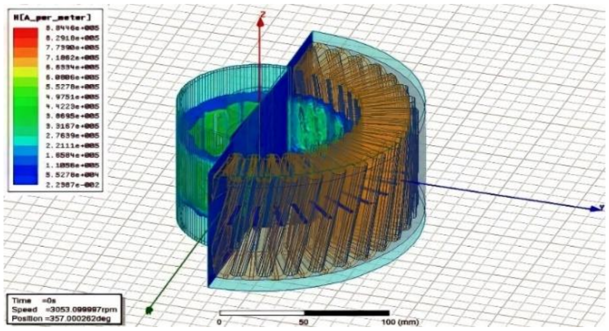


Figure 19. Intensity of the magnetic field[15]



7. CONCLUSION

The high performance electric bike uses BLDC machine as its motor. Using Maxwell 2D and 3D, the 1000W, 60V, 3000RPM motor is designed with the highest efficiency of 89.3 When a large amount of copper is added to the winding process, the torque ripple is reduced, thus the process is referred to as sinuoidel. For this design, the stator hole depth has been raised to meet torque requirements. The stator hole depth is found to be correct and can significantly reduce torque using FEM technology. "The quality of the torque can be improved with this tool. We analyzed this motor by changing the number of poles and the number of slots. 10 poles and 36 slots were used.

Reference

1. J. -H. Choi et al., "Design of High Power Permanent Magnet Motor With Segment Rectangular Copper Wire and Closed Slot Opening on Electric Vehicles," in IEEE Transactions on Magnetics, vol. 46, no. 6, pp. 2070-2073, June 2010

2. He, C.;Wu, T. Permanent magnet brushless DC motor and mechanical structure design for the electric impact wrench system. Energies , vol .11,No .24, May 2018

3. D. Gizaw, "Permanent magnet brushless dc motor having reduced cogging," Oct. 5 2018, uS Patent 5,250,867.

4. A. Mujianto, M. Nizam and Inayati, "Comparation of the slotless brushless DC motor (BLDC) and slotted BLDC using 2D modeling," 2014 International Conference on Electrical Engineering and Computer Science (ICEECS), 2014, pp. 212-214,

5. Wu Q, Tıan W Design of Permanent Magnet Brushless DC Motor Control System Based on dsPIC30F4012 ,vol.29,No.4,pp. 4223-4227 , 2012

6. Cheng, M.; Sun, L.; Buja, G.; Song, L. Advanced electrical machines and machine-based systems for electric and hybrid vehicles. Energies, vol .8 ,No.24,2015

7. M. Nizam, H. T. Waloyo and Inayati, "Design of optimal outer rotor brushless DC motor for minimum cogging torque," 2013 Joint International Conference on Rural Information & Communication Technology and Electric-Vehicle Technology (rICT & ICeV-T), 2013, pp. 1-4,

8. K. T. Chau, C. C. Chan, and C. Liu, "Overview of Permanent Magnet Brushless Drives for Electric and Hybrid Electric Vehicles," IEEE transactions on Industrial Electronics, vol. 55, no. 6, pp. 2246–2257, Jun. 2008.

9. X. Chen and G. Liu, "Sensorless Optimal Commutation Steady Speed Control Method for a Nonideal Back-EMF BLDC Motor Drive System Including Buck Converter," in IEEE Transactions on Industrial Electronics, vol. 67, no. 7, pp. 6147-6157, July 2020,

10. M. M.K, G. S. Warrier, P. Pathivil, S. Kanagalakshmi and R. Archana, "Design and Performance Analysis of Brushless DC Motor Using ANSYS Maxwell," 2019 2nd International Conference on Intelligent Computing, Instrumentation

and Control Technologies (ICICICT), 2019, pp. 1049-1053,

11. Korkosz, M.; Prokop, J.; Pakla, B.; Podskarbi, G.; Bogusz, P. Analysis of open-circuit fault in fault-tolerant BLDC motors with different winding configurations. Energies, vol .13,No.27,2020

12.M. Nizam, H. T. Waloyo and Inayati, "Design of optimal outer rotor brushless DC motor for minimum cogging torque," 2013 Joint International Conference on Rural Information & Communication Technology and Electric-Vehicle Technology (rICT & ICeV-T), 2013, pp. 1-4,

13. I. Hofman, P. Sergeant and A. Van den Bossche, "Influence of Soft Magnetic Material in a Permanent Magnet Synchronous Machine With a Commercial Induction Machine Stator," in IEEE Transactions on Magnetics, vol. 48, no. 4, pp. 1645-1648, April 2012,

.14. Hwang, M.-H.; Lee, H.-S.; Yang, S.-H.; Cha, H.-R.; Park, S.-J. Electromagnetic field analysis and design of an efficient outer rotor inductor in the low-speed section for driving electric vehicles. Energies, vol .12,No .19,2019

15. Yaz M., Çetin E. brushless DC motor driver design. 3rd National Design, Manufacturing and Analysis Congress, Issue: 2, Volume: 2 pp. 231-239,2021

16. He, C.;Wu, T. Permanent magnet brushless DC motor and mechanical structure design for the electric impact wrench system. Energies,vol.11,Nol. 24,2018

17. S. Dunkl, A. Muetze and G. Schoener, "Design Constraints of Small Single-Phase Permanent Magnet Brushless DC Drives for Fan Applications," in IEEE Transactions on Industry Applications, vol. 51, no. 4, pp. 3178-3186, July-Aug. 2015,.

18. J. Zhang, M. Cheng and Wei Hua, "Calculation of cogging torque for stator interior permanent magnet machine," Digests of the 2010 14th Biennial IEEE Conference on Electromagnetic Field Computation, 2010, pp. 1-1,

19.M. A. Hamdi , F. A. Jumaa Review of Permanent-Magnet Brushless DC Motor ,vol.11,No.14, Oct 7, 2022

20. C. . -Y. Chen, W. . -C. Chan, T. . -C. Ou, S. . -H. Yu and T. . -W. Liu, "Sliding mode speed control of Brushless DC Motor using Pulse-Width-Modulated current regulator," 2009 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, 2009, pp.