Advanced Design of DC Machines Using Finite Element Method Simulator

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Abstract

Given the importance of DC machine in the industrial field and with the technological development, researchers are interested in developing the design of DC machine of all kinds. In this work, an advanced design of different type for DC machines using finite element method simulator. Design series DC machine, shunt DC machine and compound DC machine were implemented using Ansys RMXprt and study electromagnetic phenomena in Maxwell software, we will study flux lines and magnetic flux density and identify areas of temperature distribution. The speed and torque rates for each design are evaluated with consideration of time. Then, a 3D design of a compound DC machine and series DC machine was created to evaluate the difference between the DC machine types.

Keywords: compound DC machine, Ansys Maxwell, finite element method (FEM). Magnetic flux density.

1. Introduction

DC machine has been used since ancient times for their importance in industrial systems because its control is simple and reliable in operating conditions [1-2].

There are several types of DC machines, including series DC machine [3], shunt DC machine and compound DC machines. They differ from each other according to the way the field is connected in parallel or in series. Ansys program is based on the Finite Element Method (FEM) to solve the complex calculations in the system in order to analyze and solve the equations related to the flux and electromagnetic of a DC machine. [5][6], ,István Kovács and Kornél Sarvajcz [7] studied Simulation of a series DC motor using ANSYS, Bekir Gecer and N.Fusun Oyman Serteller [8] investigate Switched Reluctance Motor Analysis using ANSYS/Maxwell The result is a flux analysis of a SRM, Tushar Waghmare et al [9] conducted design of a BRUSHLESS DC MOTOR USING ANSYS, Zhaohui Zeng and Ewen Ritchie [10] found A Method for Torque and Speed Determination for a Compound DC Motor, Md Akram Ahmad et al [11] defined Speed control of a DC motor using Controllers, Wei Jie Feng et al [12] investigated Design and Simulation of PID parameters self-tuning based on DC speed regulating system, Jesús U. Liceaga-Castro et al [13] studied a Series DC Motor Modeling, Olga V. Tikhonova and Anatoliy T. Plastun [14] investigate Electromagnetic Torque Calculation of Induction Motor of ANSYS, the results optimal of electromagnetic torque calculation, Bedoud Khouloud et al [15] presented Modeling and Fuzzy logic of a PWM Converter Feeding DC Machine, The DC machine has simple structure and models and the various phenomena in this machine can be studied through a design[16]. The DC machine gains high efficiency in work and this is due to the large torque values and the simple nature of the design [4].The current study differed from the previous studies in terms of design type, where the DC machine is designed that combines the characteristics of series DC machine and shunt DC machine[7][26]

In this work we will design a shunt DC machine and series DC machine and compound DC machine, we will know the speed and torque of each design, In Ansys Maxwell we are shown the path of the flux line and Magnetic flux density and points of concentration of temperature, And 3D design each series DC machine and compound DC machine and note the differences between them.

2. DC machine

The DC machine in the structure contains two types of compounds, the motor winding and the field coil, which determines the type of DC machine. In the rotor we find the motor windings. It is known that DC machine generate high torque with very low current consumption and with the development the application of DC increased in the middle Industrial because of its high efficiency and we find the application of this type of machine in electric cars and precision digital instruments. The control of the DC machine requires model knowledge and it is necessary to know the dynamic model of the system to improve performance. The high efficiency of the DC machine is related to the design capacity, and in order to improve the design, the dynamics of the DC machine must be known, not necessarily knowing the mathematical representation [2][17].

2.1 Construction of a DC machine

The DC machine consists of two basic parts, one is the stator and the other is the rotor. An air gap separates them. The fixed part is the outer frame of the machine and is not movable. The movable part is free to move and is the inner part of the device.

The DC machine also contains several components, as shown in Figure (1) [18], the essential parts of a DC machine are described below: Stator parts: Yoke, Pole Core, Pole Shoes, Field Coils, Interlopes.

Rotor: Shaft and core of the machine. Winding the armature, commutator and brushes as shown in Figure 1

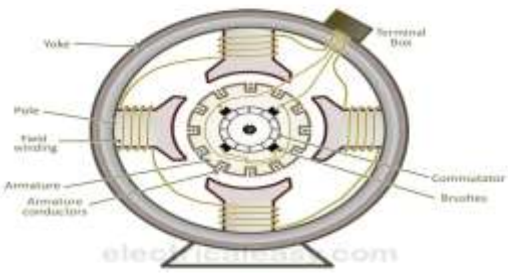


Figure.1. Construction of a DC machine.

2.2 principle of electric motor

The work of electric motors depends on electromagnetic induction around each conductor in which a current passes, a magnetic field is formed, and any change in the magnetic field affects the electric field [19-20].

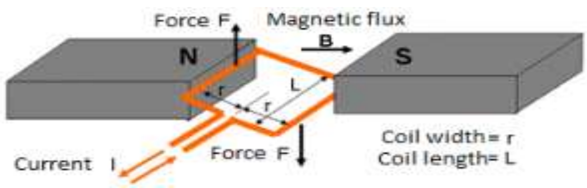


Figure. 2. Principle of electric motor.

2.3 Characteristics of DC Motors

The performance of the DC machine is evaluated based on its characteristic curves. The relation between the quantities is the kinetic characteristics that appear through the curves and the most important of these characteristics:

1. Speed and Armature current, Torque and Armature current and Speed and Torque.

The control of the flux ϕ depends on the change of flux and therefore the change of speed N. In the design of the DC machine, we explain the relation between them [3] [13].

2.4 Types of DC Motors

Types of DC machines differ according to the connection between the armature circuit and the field circuit. There are three important types. The performance of each type differs and each has suitable applications, these types are described in the following [21]:

- separately-excited DC machine
- Self-excited DC machine

A separately excited DC machine has a separate voltage. It consists of a field and a rotor winding. This structure has the advantage of controlling, In a DC self-excited machine, we find three types, (a) shunt DC machine (b) Series DC machine, (c) Compound DC machine. The type of DC machine varies according to the method of connection between the field winding and the machine. Connecting the field winding in series with the machine we get a series DC machine. (Figure. 3 (b)) [22], and (Figure 3(a)) is shunt DC machine by connecting the field winding in shunt with the armature [11]. Compound machine it is a combination between shunt DC machine and series DC machine (Fig.3 (c)).

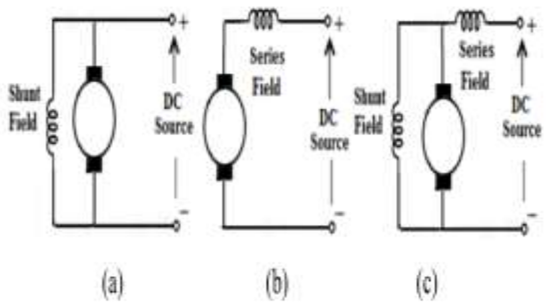


Figure 3 .Type of DC machine: (a) shunt DC machine, (b) Series DC machine, (c) Compound DC machine.

The supply voltage in a DC machine is connected with the inductance L and the resistance R. They are connected in series or shunt, and the type of DC machine is determined on that basis. The equations of the DC machine vary according to its type [23-24] in the study of the DC machine; we rely on the concepts of system theory and the mathematical model. In this system we find differential equations in each part (electrical and mechanical) and the relation between them [25] [15].

We apply the Newton and Kirchhoff laws on the machine electric model with separate excitation, we can write [2]:

$$U=E+ R\, i+L \frac{di}{dt} \quad (1)$$

$$E=K\, \Omega \quad (2)$$

Mechanical part modeling [27]

$$J \frac{dw}{dt}= T_e - T_L - f\, w \quad (3)$$

The performance of the machine is related to the torque [28]

$$T_e = K\, i \quad (4)$$

Where w is Angular speed (rad/s), E represents back electromotive force, Te is the motor torque, TL is the Load torque (N.m), and k is the back electromotive force constant i is the DC motor current (A), U is the Input voltage (V), is the J is the Inertia of the motor (Kg.m2), is the f is the Viscous friction, constant (N.m/rad/sec), R is the Armature resistance is the Armature inductance is the induced voltage.

In a series DC machine, high torque is produced when connecting a field of winding connected to a series with the rotor winding, however when the load increases, the torque decreases [27].

The DC shunt machine consist of a shunt winding connected in shunt with the armature, So it has excellent positioning and good speed regulation ability, A DC shunt motor can be described by inductance (L_a) in series with a resistance (R_a) field circuit connected across the armature having resistance and inductance value (R_f) and (L_f) respectively. For the current (i) is produced from the field current (i_f) and the machine current (i_a) according to the relation [29]:

$$i=i_a+i_f$$

In the differential equations of a compound DC machine, the flux from the field series winding and the field shunt winding are produced and are opposite [10].

$$\phi_a = \phi_{sh} - \phi_{se}$$

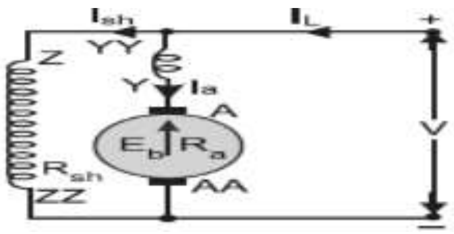


Figure 4 compound DC machine

Armature Curent $I_a = I_L - I_{sh} = I_{se}$

Field Current, $I_{sh} = V/R_{sh}$

Terminal Voltage = $E_b + I_a R_a + I_{se} R_{se}$ Electrical Power Developed = $E_b I_a$ Power Delivered to Load = $V I_L$

Where, R_{sh} ,R_{se} are the resistances of armature, field shunt winding, field series winding, I_{ch} ,I_{se} are the currents of machine, field shunt winding, field series winding,ϕ_{sh} , ϕ_{se} are the flux of device, shunt and field winding.

3. Finite Element Model of DC machine

Maxwell contains many features that help in the analysis of electrical machines. A design for a DC machine can be created in RMXprt, which gives an overview of the machine working and fast performance. We rely on pre-designed templates and add data according to the type of DC machine. The dimensions of the rotor and stator and the number of Slots in the stator, winding, number of poles of the machine and adjust the type of machine series or shunt in the DC machine, the types of DC machines differ from each other in design according to the type of connection in the field. If it is series, we get a series DC machine, and if it is a shunt we get a shunt DC machine. The most important stages for designing a DC machine, a composite starter, by introducing the machine variables and specify field series and field shunt together and .and then transfer the design to ANSYS Maxwell for study. We trace the path of the various electrical and thermal phenomena available in the program and rely on Finite Element Method to solve the equations [7-8]

4. Design DC machine

The design of the DC machine is based on accurate data on the parts of the machine Variables vary according to the type of DC machine, In Table 1 the general data of the DC machine. The number of poles 4 pole , and the speed is 750 rad/s As for the stator data in Table 2. We chose the number of slots 28 for the rotor Table 3. The series data in Table 4 and the shunt data in Table 5

TABLE 1 MACHINE DATA

Machine

Name	Value	Unit	Evaluated Value
Machine Type	DC Machine		
Number of Poles	4		
Frictional Loss	8	W	8W
Windage Loss	0	W	0W
Reference Sp...	750	rpm	

TABLE 2 STATOR DATA

Stator

Name	Value	Unit	Evaluated Value
Frame Outer Di...	300	mm	300mm
Frame Overall ...	300	mm	300mm
Frame Thickne...	30	mm	30mm
Frame Length	530	mm	530mm
Frame Material	steel_1008		
Pole Type	2		
Pole Length	135	mm	135mm
Pole Stacking ...	1		
Pole Material	D21_50		

TABLE 3 ROTOR DATA

Rotor

Name	Value	Unit	Evaluated Value
Stacking Factor	0.95		
Number of Slots	27		
Slot Type	1		
Lamination Se...	1		
Outer Diameter	110	mm	110mm
Inner Diameter	24	mm	24mm
Length	135	mm	135mm
Steel Type	D21_50		
Press Board T...	1	mm	
Skew Width	0		0

TABLE 4 SERIES DATA

Series (C)

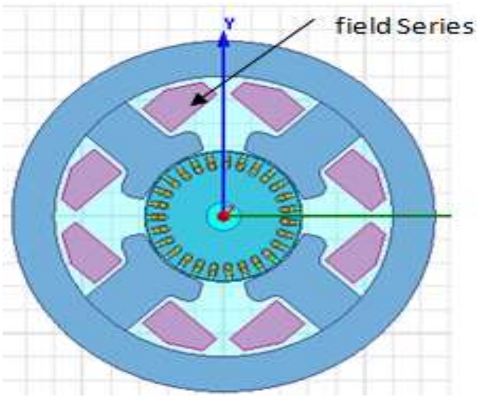
Name	Value	Unit	Evaluated Value
Parallel Branch...	4		
Conductors pe...	4		4
Number of Stra...	500		500
Wire Wrap	0	mm	
Wire Size	Diameter: ...		
Axial Clearance	3	mm	3mm
Limited Cross ...	0.5	mm	0.5mm
Limited Cross ...	0.5	mm	0.5mm
Winding Fillet	1		1

TABLE 5 SHUNT DATA

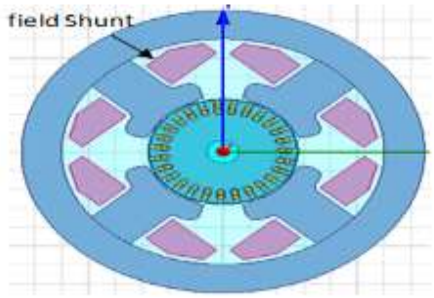
Shunt

Name	Value	Unit	Evaluated Value
Winding Type	RoundWire		
Parallel Branch...	4		
Conductors pe...	6		6
Number of Stra...	1000		1000
Wire Wrap	0	mm	
Wire Size	Diameter: ...		
Axial Clearance	3	mm	3mm
Limited Cross ...	0.6	mm	0.6mm
Limited Cross ...	0.6	mm	0.6mm

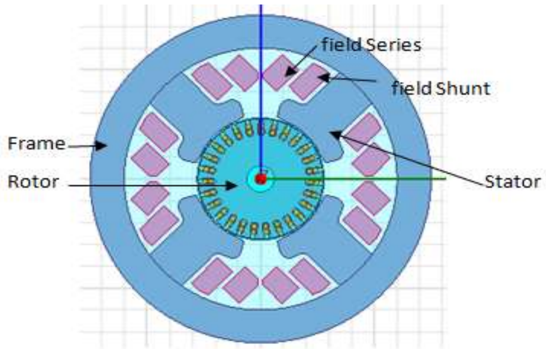
Figure 5 shows the types of DC machine that were designed by Ansys Maxwell. Figure 5(a) Series DC machine, Figure 5(b) shunt DC machine. Figure 5(c) Compound DC machine was obtained by combining series DC machine, and shunt DC machine.



(a)



(b)



(c)

Figure 5. Design shapes: (a) Series DC machine, (b) shunt DC machine, (c) Compound DC machine.

5. Design DC MACHINE 3D

The DC machine was designed in 3D. Where Figure 6 shows the design of Series DC machine and Figure 7 shows the design of Compound DC machine, we note that field series and field shunt.

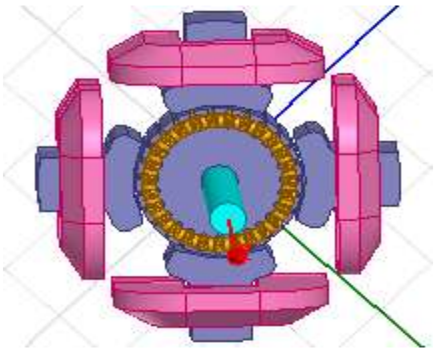


Figure.6. Series DC machine

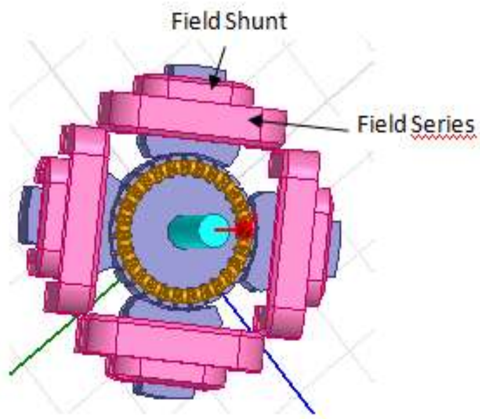


Figure 7 Compound DC machine

We relied on the finite element method to solve the magnetic field equations, Maxwell's equations describing the magnetostatic field are [30]:

$$\frac{\partial^2 A}{\partial x^2} + \frac{\partial^2 A}{\partial y^2} = -\mu J \quad (4)$$

$$\nabla \times H = J \quad (5)$$

$$B = \nabla \times A \quad (6)$$

B magnetic flux density, **H** magnetic field intensity vector, **J** is the applied current density, **μ** permeability of the magnetic material.

6. Results and Discussion

The simulation results obtained from the design of the types of DC machine, which are represented in the speed, torque, temperature, flux lines and magnetic flux density.

6.1 Series DC machine

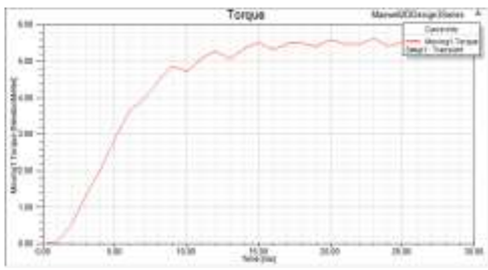


Figure.8. torque curve

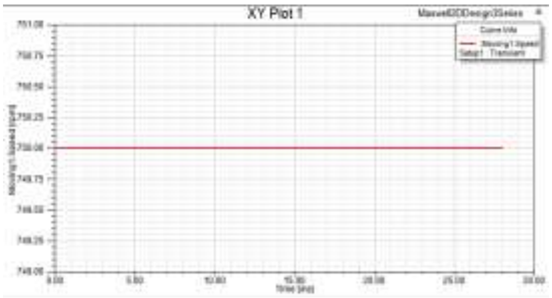


Figure.9. speed curve

Through the results of the design of the DC machine series, we note that the value of the speed is fixed at the value of 750rpm (Fig. 9), while the value of the torque starts from 0 until it reaches 5.5 Nm and then is constant (Fig. 8)

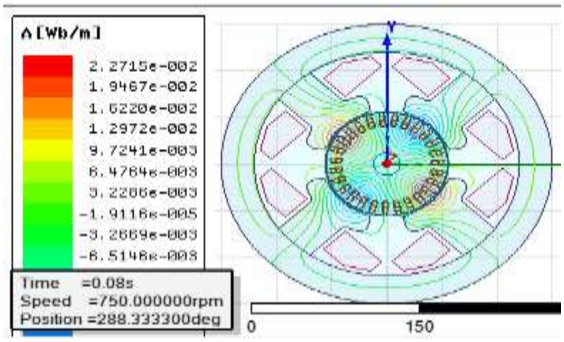


Figure 10.Flux Lines.

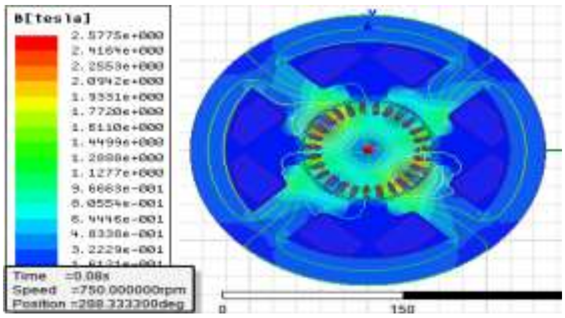


Figure 11.Magnetic flux density

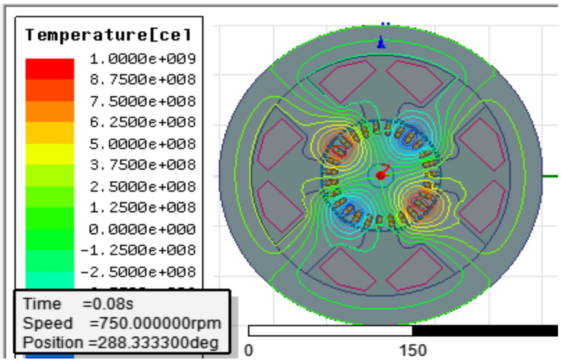


Figure 12.Temperature.

The results show the forms of flux line, magnetic flux density, and temperature for a series DC machine, Where we observe large values at the level of the coils for each of the flux line Figure 10 and magnetic flux density figure 11 ,temperature figure 12.

6.2 Shunt DC machine

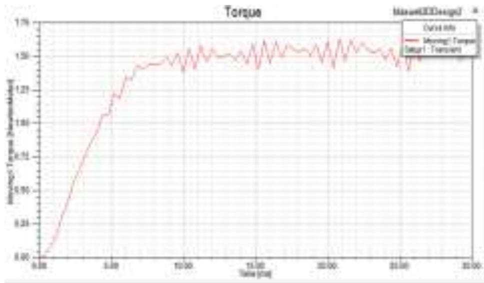


Figure.13. torque curve of a shunt DC machine

It appears that the value of the torque rises until it is constant at 1.5

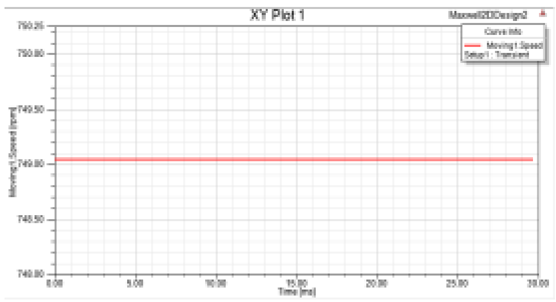


Figure.14. Speed curve of a shunt DC machine

In the design of the shunt DC machine, it is clear that the model is very similar to the design model of a series DC machine, and from the design results the flux line, magnetic flux density, and temperature appear close to the results of the series DC machine, The most important difference between them is the torque of the DC machine.

6.3 Compound DC machine

From the results of designing a compound DC machine, Figure 17 shows that the flux line is spread between the rotor and the stator, and from Figure 18 we notice the distribution of magnetic flux density inside the machine and the same distribution of temperature in Figure 19, the torque curve is shown to rise to the point of stability at 4.5.

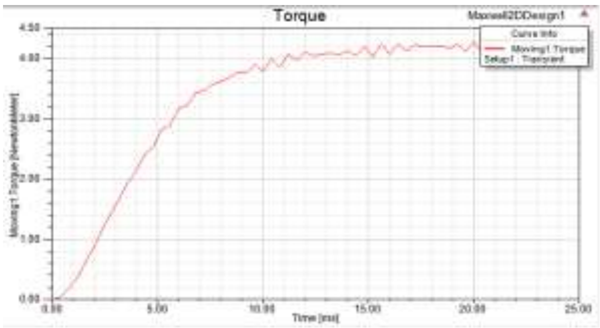


Figure.15. torque curve

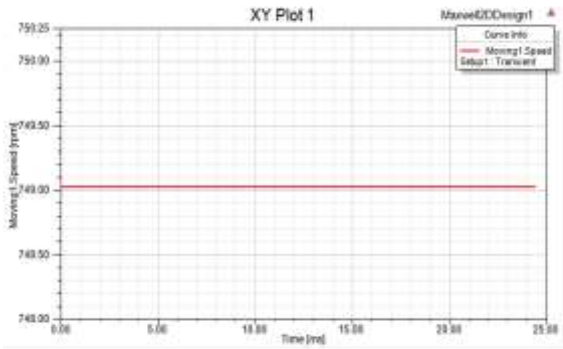


Figure.16. Speed curve

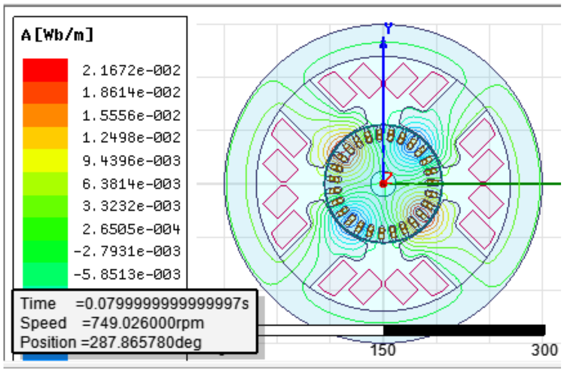


Figure .17.Flux Lines.

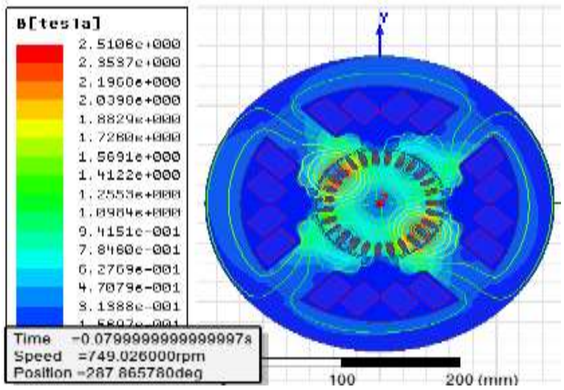


Figure .18.Magnetic flux density

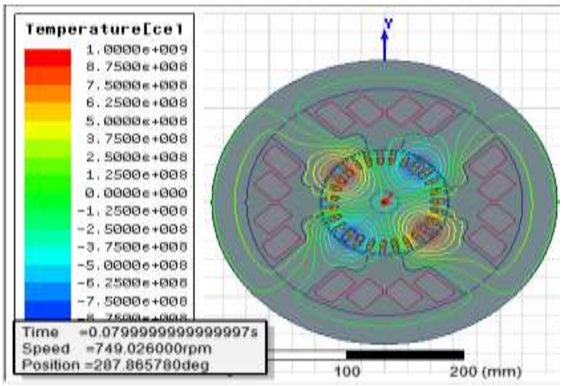


Figure .19.Temperature.

7. CONCLUSION

In this study, we designed a DC machine in Ansys RMXprt and showed flux lines, magnetic flux density and temperature in Ansys Maxwell.

And our focus was on studying the speed and torque of the DC machine types, series DC machine, shunt DC machine and compound DC machines, FEM was carried out to study DC machine types and from observing the perfect distribution of flux lines and magnetic flux density and this indicates the efficiency of the process,

It is evident that the torque values were average in the compound DC machine compared to the other DC machines.

Through comparison of the two designs, it is found that the compound DC machine has a suitable torque and a more widespread flux distribution.

8. FUTURE WORK

In future works, the DC machine can be transferred to the Ansys Simplorer and it can be controlled, the parameters of the machine can be changed according to the appropriate method.

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