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Design of Radial Flux PM Synchronous Motor for EV Applications

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Abstract: High-performance electric propulsion systems are becoming increasingly important as the automotive industry rapidly shifts to electric cars (EVs). The electric motor is an essential part of these systems as it determines the power, efficiency, and overall performance of the vehicle.This project uses Altair Flux, a full-featured finite element analysis (FEA) software suite, to build and optimize a radial flux motor (RFM) with permanent magnet synchronous motor (pmsm) . The main goal is to increase the power density and efficiency of the electric propulsion system for electric cars by utilizing Altair Flux's simulation and analytical capabilities.

The purpose of this project is to showcase the design and optimization capabilities of electric vehicle propulsion systems, with a focus on Radial Flux P.M Synchronous Motors. One of the crucial areas that has to be addressed in order to maintain high efficiency and decrease overall costs is reducing the quantity of magnet material used. measuring the motor at various frequencies and obtaining the characteristics of speed versus torque It attempts to create an RFM that satisfies the stringent criteria of EV applications in terms of efficiency, power density, and reliability by thorough simulation and analysis. The study's findings may help the automobile sector embrace electric vehicles more widely and provide environmentally friendly transportation options.

Keywords: radial flux motor(RFM), high efficiency, low cost, magnet thickness, speed torque of various frequencies , permanent magnet synchronous motor(pmsm)

I. INTRODUCTION

The need for personal mobility and the growing worldwide population have resulted in a sharp rise in the demand for oil, which has caused emissions and contributed to global warming. One idea to help with the energy issue and lower greenhouse gas emissions is to employ electric vehicles that run on batteries. Air quality and the environment as a whole are deteriorated by the emissions from internal combustion engines, which include sulfur dioxide (SO2), hydrocarbons (HC), particulate matter (PM), carbon dioxide (CO2), carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM).

One of the main greenhouse gases causing climate change is carbon dioxide, which traps heat in the atmosphere and causes global warming. Because carbon monoxide prevents oxygen from entering the bloodstream, it immediately endangers people's health. Unlike conventional gasoline or diesel cars, electric vehicles (EVs) are powered by rechargeable batteries and do not emit exhaust emissions.

EVs have the ability to improve air quality and mitigate climate change by reducing greenhouse gas emissions and air pollution by using electricity as a fuel source.

Electric cars can also aid in lowering reliance on fossil fuels. Clean and sustainable energy may power transportation with electricity as renewable energy sources like solar and wind power become more widely available. Several motor types are used to power electric cars, with the permanent magnet synchronous motor (PMSM) being one of the most often used varieties.

The PMSM offers several benefits over other kinds of motors, including being lightweight and efficient, which allows it to generate large amounts of power without consuming a lot of room or energy.

These motors aim to improve upon their current state, and one method to achieve this is by optimizing the size and placement of the magnets inside the motor. In this study, the effects of the magnets on the motor's performance—that is, its efficiency and energy consumption—were the focus of the investigation.

Overall, engine performance and energy efficiency may be increased by adjusting the magnets utilized in electric car motors.

Permanent magnet (PM) motors with radial flux have several benefits.

High torque: The radial design makes it possible for the magnetic field to interact with a bigger air gap between the stator and rotor. Because of the bigger air gap, the magnetic field has a stronger leverage point, which leads to a high torque output for the size of the motor.

The structure of this document is as follows: The literature review needed for the motor's design and different parameter analysis is provided in Section II. The Radial flux PMSM setup, modeling, and important design parameters are covered in Section III. The comparison and analysis of the primary simulation results are shown in the first section of Section IV. The second section discusses the torque versus speed at various frequencies. The concluding remarks are included in Section V.

II. LITERATURE REVIEW

The PMSM, also known as the permanent magnet synchronous motor, is well-known for its straightforward design, dependable performance, compact size, light weight, low inertia and quick reaction, high power factor and high power density, high efficiency, and position as the preferred electric vehicle motor. The performance of the motor is also significantly impacted by modifications made to the permanent magnet (PM) structure of the PMSM rotor. PM structures are separated into surface and interior categories. Permanent magnets placed on the surface are often surface structures.[1].

Topology of motors. The permanent magnet synchronous motor's variable rotor construction allows it to adapt to the various performance structure needs of various electric cars, giving it a diversity of topology.

Permanent magnet synchronous motors come in two varieties, surface mount and embedded, depending on where the rotor magnet is positioned. The embedded kind is typically used in electric vehicles, as seen in the rotor construction of the Toyota Prius primary drive motor. [2]

The windings are turned on one at a time, creating a revolving magnetic field. When the stator is turned on, an electromagnetic force is generated, which attracts the magnets on the rotor. As a result, the rotor lines up with the electromagnetic poles of the stator. This alignment is the fundamental concept of Permanent Magnet Synchronous Motors (PMSM).The PMSM rotates according to the position of the rotor, which is established by a Hall Effect sensor inside the motor.

The sinusoidal back electromotive force (EMF) that the motor generates affects the torque that it produces.[3]

The authors of [4] explain how changes to the magnetic materials—such as NdFeB, Sm2Co3, and Sm2Co17—installed on the rotor impact efficiency. The different magnet materials have different magnetic flux densities, which affects the output coefficient and other metrics associated with it. Finally, it was shown that NdFeB magnets provide higher efficiency. The authors describe in [5–8] the design methodologies, standards, and optimization techniques that may be applied to enhance motor design and validate analytical computations utilizing finite element analysis.

Since there are enough charging stations in the big cities, EVs have become more and more popular in recent years. Likewise, an electric motor is used by EVs in place of internal combustion engines. The characteristics and constraints of the electric motors utilized to increase the EV's efficiency were examined in the study that was given.[9].

Nevertheless, there are several drawbacks to the dispersed winding motor and inside permanent magnet, including excessive temperature increase, poor efficiency at low speeds, and significant torque ripple [10]. Thus, it is necessary to make certain structural adjustments in order to enhance the IVPM motor's operating performance.

III. RADIAL FLUX MOTOR DESIGN

The Ampere 390V vehicle's radial flux motor is chosen, and table I displays the RFPMM's operating parameters.

Table .1 OBTAINED DATA FROM RADIAL FLUX MOTOR

Electric quantities	values
Power (W)	1045.5
Current (I)	22.89
Voltage (V)	390
Rated torque(N.m)	3.152
Efficiency(%)	91
speed	1500

Measurements have been made of the radial flux motor's design dimensions, including its outer and inner diameters, the stator slot's height and width, the permanent magnet's length and breadth, etc. The stator of a conventional radial flux BLDC motor has a permanent magnet rotor.

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A yoke attached to the stator is covered with individual electromagnetic coil-wrapped "teeth." As alternating magnetic poles, teeth function. Torque is produced by the interaction between the rotor's magnetic poles and the teeth's alternating magnetic flux. Here, however, an externally spinning radial flux motor has been used as the motor. In contrast to an embedded motor, the surface mount PM type under investigation is less expensive and has a simpler structure. Second, because surface mounted magnets are in direct contact with the rotor surface, they provide more efficient cooling systems and improve heat dissipation. As a consequence, the motor performs better thermally and is guaranteed to run within ideal temperature ranges, which is crucial for preserving longevity and efficiency. For Permanent Magnet Synchronous Motors (PMSMs) in Electric Vehicles (EVs), choosing the appropriate magnet material is essential to get the best possible performance and efficiency. Neodymium-based magnets—like neodymium-iron-boron (NdFeB)—are typically used because of their high magnetic strength, which enables smaller motor designs and better power densities. With their exceptional energy efficiency, these magnets allow electric vehicles to go farther between charges. Neodymium magnets also show good temperature stability, which guarantees steady performance even under a range of working circumstances. It is crucial to take into account the sustainability of these materials' supply chains and their influence on the environment.

Although they are more expensive, alternatives like samarium-cobalt (SmCo) magnets may be selected for situations where environmental concerns or improved temperature stability are important factors. NeFeB1370_1273 is therefore taken into consideration for investigational purposes due to its high saturation flux density.

Two fundamental characteristics of the stator and rotor core are the B-H curve and the iron losses. The fundamental construction of the motor can be constructed from laminated silicon material.

Lower iron losses are achieved using thinner laminated material, but at a higher cost. M350-50A laminated steel is employed in this study due to its low loss density and high saturation flux density.

The specifications and parameters required for the design of PMSM is given in Table and Table 3.

Table.2.PMSM's Stator and Rotor core design parameters.

Quantity	Value (mm)
Rotor Outer diameter	68
Rotor inner diameter	20
Rotor poles	12
length	25
Stator outer diameter	120
Stator inner diameter	70
No of Stator slots	36

The slot parameters are described intable2.

Quantity	Value(mm)
Slot height	14.85
Slot width(bottom part)	4.576
Intermediary height of the slot (upper part)	1.144
Slot width (upper part)	3.268
Height of the slot opening	0.6537
Width of slot opening	0.6537

The coil parameters are described in table 3.

parameter	values
No. of turns per coil	6
No. wires in hand	4
Wire diameter	1.102mm
Inter-wire space	0.005mm

The radial view of motor for the above dimensions is shown below in figure 1.

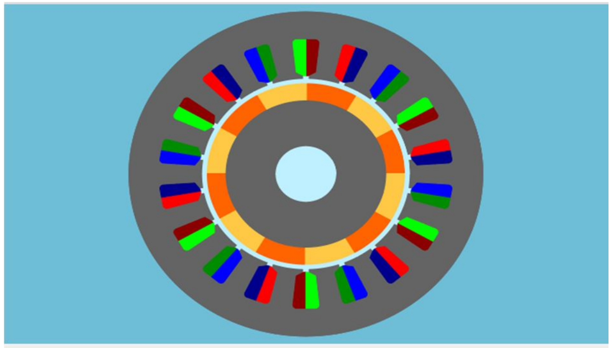

Figure1: Radial view of the designed motor.

After examining many winding topologies, mmf analysis, winding factors, harmonics, the flux distribution in air gaps, and in cores, the aforementioned desirable dimensions are achieved.
This research examines the optimization of magnet mass and cost reduction with improved efficiency and decreased cogging torque Is fractional slot was implemented by the winding topology.

A. *The Winding Topology*

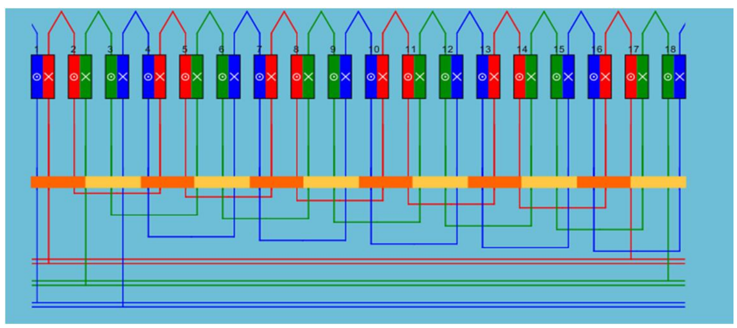

Figure3: stator winding connection

B. *Magnet Polarization*

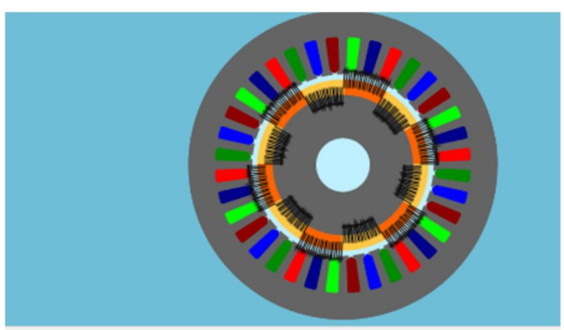

Figure4: polarization of flux lines.

IV. RESULTS

The comparative examination of several performance metrics for two distinct air gaps is presented in Tables (a) and (b). 1 mm and 1.5 mm by altering the number of wires in hand, turnper coil, and magnet thickness, accordingly.

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Table(a):Effect of variation of magnet thickness,turnsper coil and wires in hand on performance parameters for 1mm air gap.

S.NO	MAGNET THICKNESS	MASS OF MAGENT	TURNS PER COIL	NO.OF WIRES IN HAND	EFFICIENCY %	MECHANICAL POWER OUT PUT (W)	OUTPUT TORQUE	SPEED
1	6	0.222	6	4	91.642	491.638	3.130	1500
2	6	0.222	7	3	91.502	432.750	2.755	1500
3	6	0.222	8	2	91.111	320.550	2.041	1500
4	7	0.246	8	3	91.599	516235	3.284	1500
5	7	0.246	7	2	90.886	260.739	1.660	1500
6	7	0.246	6	3	91.370	345.648	2.200	1500
7	10	0.346	7	1	86.978	85.906	0.540	1500
8	10	0.346	6	2	90.470	195.906	1.247	1500
9	10	0.346	8	1	88.588	121.105	0.700	1500

Table(b):Effect of variation of magnet thickness ,turnsper coil and wires in hand on performance parameters for 1.5mm air gap.

S.NO	MAGNET THICKNESS	MASS OF MAGENT	TURNS PER COIL	NO.OF WIRES IN HAND	EFFICIENCY %	MECHANICAL POWER OUT PUT (W)	OUTPUT TORQUE	SPEED
1	6	0.218	6	4	91.047	453.288	2.886	1500
2	6	0.218	7	3	90.945	397.593	2.531	1500
3	6	0.218	8	2	90.649	294.215	1.873	1500
4	7	0.250	8	3	90.667	295.355	1.880	1500
5	7	0.250	7	2	90.520	241.654	1.538	1500
6	7	0.250	6	3	90.888	320.150	2.036	1500
7	10	0.340	7	1	87.620	83.488	0.5315	1500
8	10	0.340	6	2	90.256	183.963	1.171	1500
9	10	0.340	8	1	88.737	114.543	0.7292	1500

From above, it is clear that efficiency essentially stays constant even as the permanent magnet's breadth varies. This feature makes it possible to optimize the thickness of the magnet, offering a chance to reduce material consumption without compromising effectiveness .The rows in the above two tables that have one wire in hand and seven turns per coil are removed because their output power is insufficient. Additionally, the efficiency is better for six revolutions with four wires in hand, but at the expense of lower torque and faster speeds. As a result, the above chart shows that the ideal parameters to take into consideration are 7 mm of magnet thickness, 7 turns per coil, and 8 no of wires. The 6mm thickness is not taken into consideration even if it fits our goal since a 7mm magnet may be used to alleviate any saturation that may arise from the 6mm thickness magnets .Also, the field weakened as a result of the air gap increasing from 1 to 1.5 mm, increasing speed.

Efficiency and power output are almost same for both air gaps. The various graphical outputs are shown below.

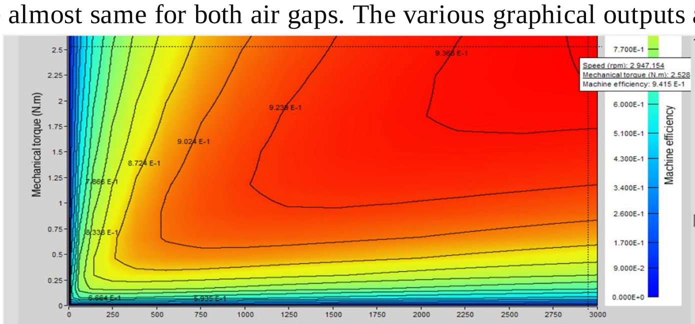

Fig: 5(a). efficiency of 1mm air gap

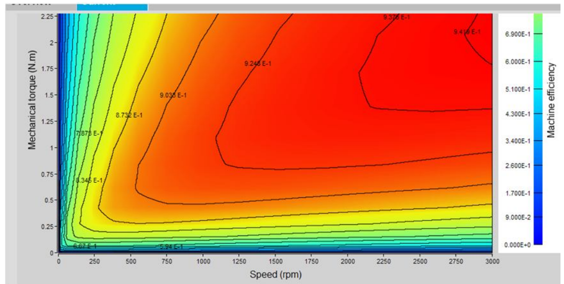

Fig:5(b). efficiency of 1.5 mm air gap.

Figure: Efficiency maps for 7 mm magnet thickness,6 turns per coil and 4 wires in hand for 1mmairgap, 1.5mmairgap
The motor's efficiency maps for 1 mm and 1.5 mm air gaps are shown in Figures (a) and (b), respectively. The area of high efficiency where a motor is preferred to run is represented by the red area with closed contour lines.The suggested motor loses efficiency at speeds lower than 250 rpm. A motor with high efficiency can run at speeds higher than 1500 rpm.

A. Power and Speed of the Motor

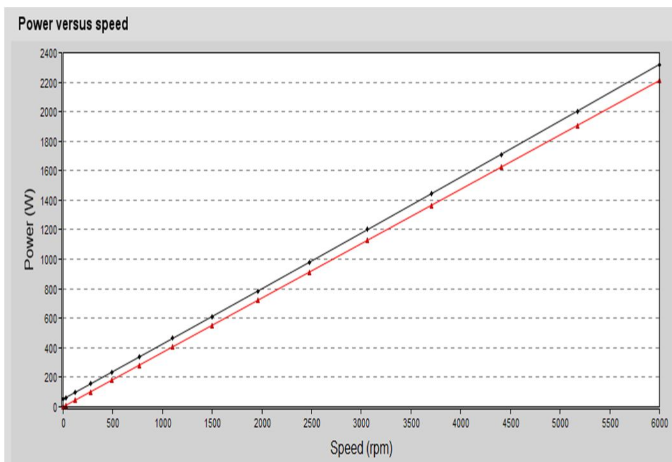

Fig:6(a). power and speed of 1mm air gap.

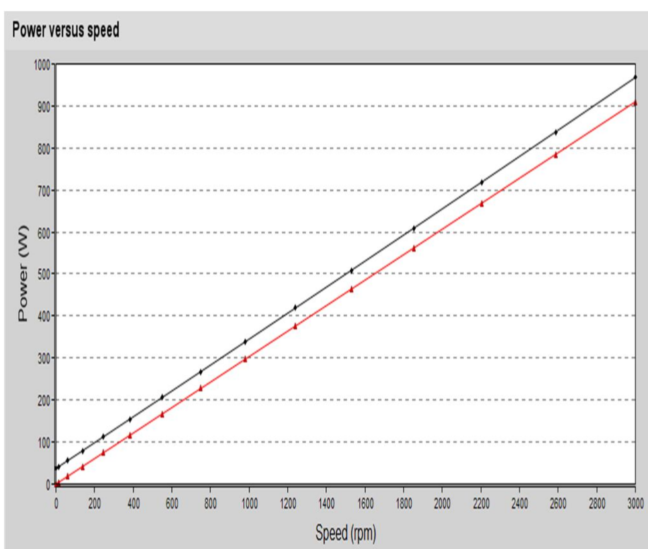

Fig: 6(b).power and speed of 1.5mm air gap.

From above figure Since power and speed are proportionate to one another in both, they have no influence on the motor.

B. Cogging Torque

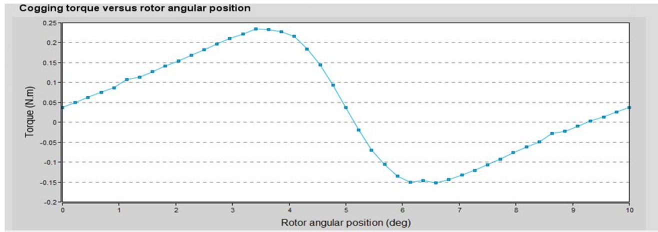

Fig7(a) cogging torque of 1mm.

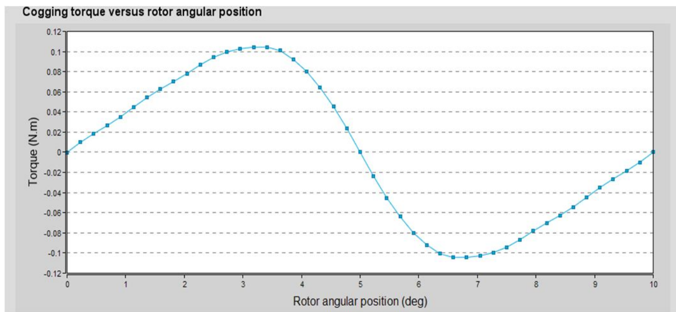

Fig 8(b). cogging torque of 1.5mm.

Figures 7(a) and 7(b) show the cogging torque vs rotor angular position for 1mm and 1.5mm air gaps. For 1 mm and 1.5 mm air gaps, the maximum cogging torque is 0.22 Nm and 0.18 Nm, respectively. An increase in air gap weakens the field, which reduces cogging torque.

C. Speed and Torque Varitaion for Different frecuency

BY USING V/f TO OBSERVE TORQUE AND EFFICIENCY AT DIFFERENT SPEDD AIR GAP; 1mm

S.NO	frequency	speed	torque	efficiency	Mechanical Output power	Electrical Output power
1	300	3000	3.132	94.113	983.987	1045.538
2	220	2200	3.132	93.313	1063.385	1588.00
3	200	2000	3.195	92.912	669.179	720.232
4	170	1700	3.275	92.098	582.962	632.979
5	150	1500	3.306	91.379	519.353	568.340
6	100	1000	3.385	88.282	354.527	401.584
7	50	500	3.512	79.565	183.898	231.128

BY USING V/f TO OBSERVE TORQUE AND EFFICIENCY AT DIFFERENT SPEDD AIR GAP; 1.5mm

S.NO	frequency	speed	torque	efficiency	Mechanical Output power	Electrical Output power
1	300	3000	2.896	94.31	909.61	967.75
2	220	2200	2.896	93.024	667.305	1508.685
3	200	2000	2.949	92.549	617.622	667.349
4	170	1700	3.015	91.611	536.768	585.919
5	150	1500	3.041	90.796	477.737	526.165
6	100	1000	3.107	87.358	325.355	372.441
7	50	500	3.212	77.969	168.17	215.689

According to the data above, speed and efficiency increased along with frequency.

V. CONCLUSION

The motor's efficiency, torque production, and flux distribution were examined in the simulation results under several operating circumstances, and changes in magnet thickness were also noted. As a consequence, the torque output of the radial flux pm synchronous motor has improved and magnetic losses have been reduced, which is encouraging. Furthermore, flux barriers efficiently guide the magnetic flux, enhancing rotor synchronism and increasing efficiency to 94.90% while operating at broad speeds.

Hence, creating a radial flux PMSM that is tailored for high-performance electric machines with increased efficiency and decreased losses advances motor technology for a range of industrial uses. To confirm the simulation results and investigate more avenues for improving the motor's efficiency and performance, more study and development are required.

Our knowledge of the parameters of motor performance was further enhanced by the examination into the effects of different air gap lengths. An increase in the air gap distance was found to significantly reduce cogging torque, even while changes in efficiency and other characteristics were somewhat steady across varied air gap configurations. The same suggested motor produced a higher-power motor with a faster speed that is appropriate for highway travel when the turns per coil and the number of wires were changed.

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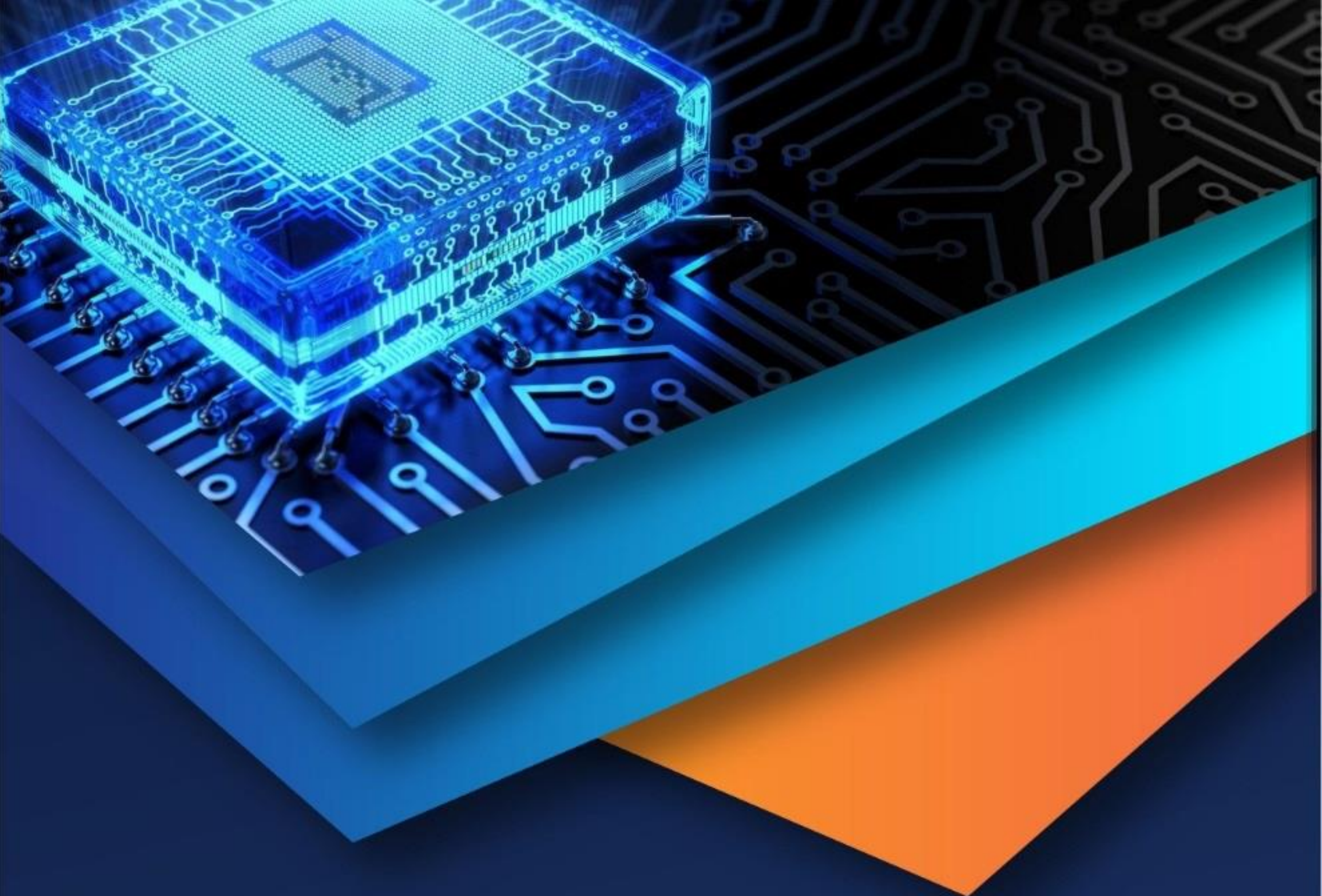

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