OPTIMIZATION IN PMSM FOR ELECTRIC VEHICLE

A MINI PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

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TABLE OF CONTENTS

ABSTRACT

This project focuses on optimising the magnetic thickness of the permanent magnet used in a Permanent Magnet Synchronous Motor (PMSM) for electric three-wheeler applications. Specifically, it aims to analyse the impact of altering the thickness of Curved shape Neodymium Ferrite Boron (NdFeB) magnets on various performance parameters such as torque, efficiency, losses, and flux. The optimization process involves analytical calculations to compare the existing PMSM design with the optimised design. FEA simulations are conducted to accurately determine the magnetic flux distribution within the motor and evaluate the desired performance parameters. The results of the analysis will be presented using graphs, charts, and tables, allowing for easy comparison between the two designs. The study's findings will help identify the optimal magnet thickness for the PMSM rotor, which can provide maximum torque output, increased efficiency, reduced losses, and improved flux distribution. The outcomes of this project have significant relevance to the electric three-wheeler industry. They can offer valuable insights into designing PMSMs that deliver superior performance with improved efficiency and reduced energy consumption. Additionally, the optimised rotor design can help extend the range of electric three-wheelers, making them more practical and appealing to consumers.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

S NO.	SYMBOL	EXPANSION
1	PMSM	Permanent Magnet Synchronous Motor
2	IPM	Interior Permanent Magnet
3	SPM	Surface mounted PM Motor
4	PMAC	Permanent Magnet AC Motor
5	FSPMSM	Flux Switching PM Synchronous Motor
6	FEA	Finite Element Analysis
7	EV	Electric Vehicle
8	ICE	Internal Combustion Engine
9	BLDC	Brushless DC Motor
10	EMF	Electromotive Force
11	PF	Principal Functions
12	CF	Constraint Functions
13	DSP	Digital Signal Processing
14	PID	Proportional Integral Derivative
15	PWM	Pulse Width Modulation
16	MMF	Magnetomotive Force
17	FAST	Functional Analysis System Technique
18	NdFeB	Neodymium Ferrite Boron

CHAPTER 1

INTRODUCTION

1.1. ELECTRIC VEHICLE

Today, the world has shifted towards electric vehicles (EVs) due to environmental concerns, technological advancements in battery technology, government policies that encourage adoption, growing public awareness about the benefits of EVs, and automaker investments in EV development. This shift is driven by the desire to reduce emissions, save costs, improve performance, and increase convenience.

Such Electric Vehicles, using motors as the driving mechanism, when compared with traditional fuel-engine vehicles have large starting torque, faster acceleration, no gearbox, and reduced noise, as well as no exhaust emissions during driving. These vehicles are gradually becoming a means of transportation for people. At present, electric vehicles use rechargeable batteries as energy input and the capacity of each charge is limited.

To increase the cruising range of electric vehicles it is necessary to reduce the weight and energy loss of the vehicle as much as possible, therefore, the requirements of small volume, lightweight, and high efficiency for the power component and motor drive system are put forward. EV technology is rapidly evolving, with advancements in battery technology, charging infrastructure, and range.

PMSMs are commonly used in Electric Vehicles (EVs) due to their high performance, reliability, and efficiency. The adoption of PMSMs in EVs has increased in recent years, as advances in materials and manufacturing techniques have led to improvements in the performance and efficiency of PMSMs.This is the reason why many citizens opt for EV rather than other conventional vehicles.

1.2. MOTOR

Motors play a crucial role in electric vehicles (EVs) as they provide the power to move the vehicle. EVs use electric motors instead of internal combustion engines (ICEs) to drive the wheels. The motor receives power from the battery and converts it into rotational force, which drives the wheels through a transmission or a direct drive system. The type of motor used in an EV can affect its performance, efficiency, and driving range. A high-performance motor can provide better acceleration, while an efficient motor can extend the vehicle's driving range. Therefore, the selection of a motor is a critical decision for EV manufacturers.

The most common types of electric motors used for electric vehicles (EVs) are Brushless DC (BLDC) Motor, Induction Motor, Permanent Magnet Synchronous Motor and Permanent Magnet AC (PMAC) Motor. BLDC and PMAC motors are preferred for EVs due to their efficiency and high torque output. The choice of motor for an EV depends on factors such as the vehicle's weight, performance requirements, and cost considerations.

A Permanent Magnet Synchronous Motor (PMSM) is a type of electric motor commonly used in Electric Vehicles (EVs) due to its high efficiency, high performance, power density, and torque-to-inertia ratio. PMSMs have permanent magnets mounted on the rotor, which interacts with the stator's magnetic field, causing the rotor to rotate. PMSMs are popular for EVs due to their high performance, reliability, and efficiency, making them well-suited for applications that require high torque and power output.

1.3. PMSM

PMSM stands for Permanent Magnet Synchronous Motor, which is a type of synchronous electric motor. Synchronous motors are characterised by the fact that the rotor rotates at the same speed as the rotating magnetic field generated by the stator's current. PMSMs are specifically categorised as synchronous motors because the interaction between the permanent magnets on the rotor and the stator's magnetic field creates a rotating magnetic field that drives the rotor's motion.

It uses permanent magnets on the rotor to generate a magnetic field. The rotor rotates within a stator consisting of windings, and the interaction between the rotor's magnetic field and the stator's magnetic field causes the rotor to rotate. PMSMs are known for their high efficiency, power density, and torque-to-inertia ratio, and they are commonly used in Electric Vehicles (EVs) due to their high performance, reliability, and efficiency.

1.3.1. CONSTRUCTION OF PMSM

The construction of a PMSM (Permanent Magnet Synchronous Motor) consists of two primary components: the rotor and the stator.

Rotor:

The rotor of a PMSM is made up of permanent magnets that are arranged in a specific pattern, such as a surface-mounted or interior permanent magnet configuration. The permanent magnets generate a magnetic field that interacts with the magnetic field of the stator to produce the motor's rotation. The rotor also has an axis that allows it to rotate freely within the stator.

Stator:

The stator of a PMSM consists of a series of copper windings that are arranged in a specific pattern to produce a magnetic field when an electrical current is passed through them. The windings are typically arranged in a distributed or concentrated pattern and are placed within the stator's iron core. The stator's magnetic field interacts with the rotor's magnetic field to produce torque and rotation.

The combination of the rotor and stator creates a rotating magnetic field that drives the rotor's motion. The PMSM may also have various components, such as bearings, shafts, and housings, to support the rotor and stator and protect the motor's internal components.

Overall, the construction of a PMSM is designed to maximise performance and efficiency while minimising size, weight, and cost.

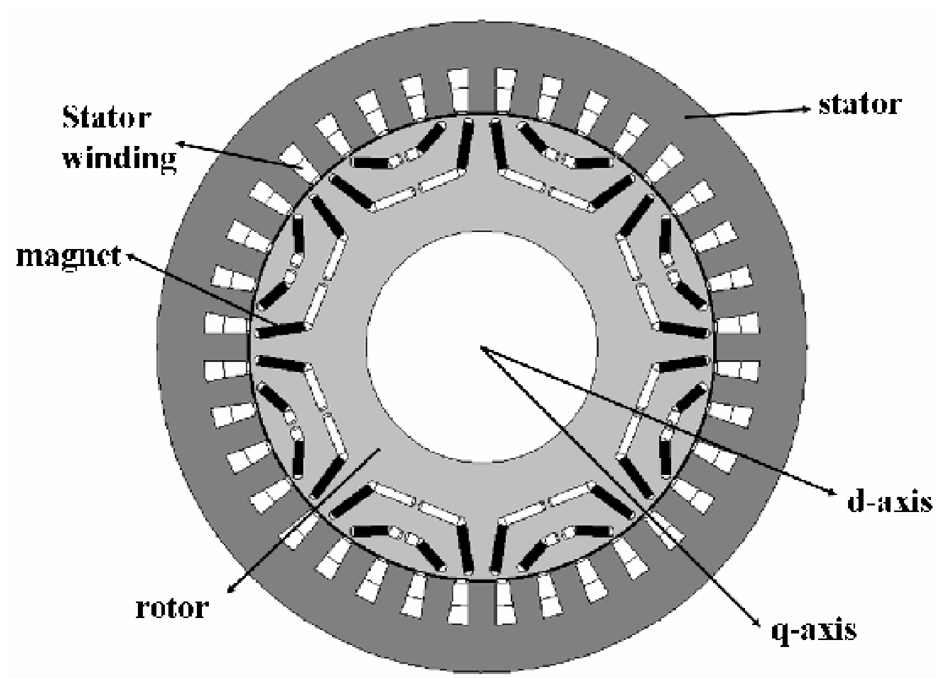


Figure 1.1 Construction of PMSM motor

1.3.2. OPERATING PRINCIPLE

The principle of operation of PMSM (Permanent Magnet Synchronous Motor) is based on the interaction of magnetic fields generated by the stator and rotor of the motor. The PMSM consists of a stator with three-phase windings and a rotor with permanent magnets. The following are the basic principles of operation of PMSM:

Stator windings: The stator windings are arranged in a three-phase configuration that produces a rotating magnetic field when energised by an AC power source. The magnetic field rotates at a synchronous speed with respect to the frequency of the AC power source.

Rotor magnet: The rotor contains a permanent magnet that produces a magnetic field that interacts with the magnetic field produced by the stator. The magnetic field of the rotor is oriented perpendicular to the magnetic field of the stator.

Electromotive force (EMF): When the rotating magnetic field of the stator interacts with the magnetic field of the rotor, it induces an electromotive force (EMF) in the rotor windings. This EMF produces a torque that causes the rotor to rotate.

Synchronous speed: The PMSM operates at a synchronous speed that is determined by the number of poles in the stator and the frequency of the AC power source. The synchronous speed of the motor can be calculated using the following formula: $N_s = 120f/P$, where N_s is the synchronous speed, f is the frequency of the AC power source, and P is the number of poles in the stator.

Control: The speed and torque of the PMSM can be controlled by adjusting the frequency and amplitude of the current supplied to the stator windings. The speed can also be controlled by varying the phase angle between the stator and rotor magnetic fields.

The principle of PMSM operation is based on the interaction of the rotating magnetic field produced by the stator windings and the permanent magnet on the rotor. The interaction between these two magnetic fields produces a torque that causes the rotor to rotate at a synchronous speed determined by the number of poles in the stator and the frequency of the AC power source.

1.3.3. CLASSIFICATION OF PMSM

PMSMs can be classified based on the arrangement of their windings and magnets, which can impact their performance characteristics. Some common classifications of PMSMs include:

1. Surface-mounted PMSM (SPMSM): This type of PMSM has magnets mounted on the rotor's surface and a stator with distributed windings. SPMSMs are typically less expensive and easier to manufacture than other types of PMSMs, but they may have lower torque density.

2. Interior permanent magnet PMSM (IPMSM): In this type of PMSM, the magnets are embedded within the rotor and arranged in a specific pattern. The stator typically has concentrated windings or distributed windings, and IPMSMs can offer higher torque density and better efficiency than SPMSMs.

3. Flux-switching PMSM (FSPMSM): This type of PMSM has both the stator and rotor with salient poles and utilises the magnetic flux linkage between them. The stator windings can be distributed or concentrated, and the rotor has no permanent magnets but instead relies on the magnetic flux of the stator to generate torque. FSPMSMs can have high torque density and efficiency.

4. Halbach array PMSM: This type of PMSM uses a specific arrangement of permanent magnets on the rotor to achieve a stronger magnetic field on one side and a weaker magnetic field on the other side. This results in a higher torque density and efficiency than other types of PMSMs.

1.4. IPMSM

An Interior Permanent Magnet Synchronous Motor (IPMSM) is an electric motor that uses a permanent magnet rotor and a stator with windings that are excited with alternating currents. In an IPMSM, the permanent magnets are mounted inside the rotor and are positioned in a way that creates a magnetic field that interacts with the stator's magnetic field to produce rotation.

The advantages of IPMSMs include high efficiency, high torque density, and good control characteristics. Due to their high efficiency, IPMSMs are commonly used in hybrid and electric vehicles, as well as in industrial and aerospace applications.

In recent years, advancements in materials science and manufacturing technology have made IPMSMs more affordable and widely available, leading to their increasing adoption in various industries.

1.4.1. SCOPE OF IPMSM

The scope of IPMSM (Interior Permanent Magnet Synchronous Motor) is quite broad and diverse due to its unique advantages and applications. Some of the common areas where IPMSMs are used include:

1. Electric and hybrid vehicles: IPMSMs are extensively used in electric and hybrid vehicles due to their high efficiency, high torque density, and good control characteristics. They help to improve the range and performance of the vehicle while reducing emissions.

2. Industrial automation: IPMSMs are used in industrial automation for various applications, including pumps, fans, and compressors. They offer high efficiency and reliability, making them ideal for continuous operation.

3. Renewable energy: IPMSMs are used in wind turbines and hydroelectric generators to convert mechanical energy into electrical energy. They offer high efficiency and reliability, making them ideal for renewable energy applications.

4. Aerospace: IPMSMs are used in aerospace applications, including electric aircraft propulsion and satellite attitude control. They offer high efficiency and lightweight design, making them ideal for space-constrained applications.

5. Home appliances: IPMSMs are used in various home appliances, including washing machines, vacuum cleaners, and air conditioners. They offer high efficiency and low noise, making them ideal for household applications.

Overall, the scope of IPMSMs is expected to increase in the coming years as more industries adopt electric and hybrid technologies and seek to improve efficiency and reduce emissions.

1.5. ADVANTAGES, DISADVANTAGES & APPLICATIONS OF PMSM

1.5.1. ADVANTAGES

PMSM (Permanent Magnet Synchronous Motor) is a highly efficient, low-maintenance electric motor that offers several advantages over other types of motors. Here are some of the advantages of PMSM:

High efficiency: PMSM has a high efficiency due to its low rotor resistance, which reduces losses due to heat dissipation. The motor can achieve efficiencies of up to 98% under certain operating conditions, making it an energy-efficient option for various applications.

High power density: PMSM has a high power density, meaning that it can deliver high levels of power output in a compact and lightweight package. This makes it an ideal choice for applications that require high power and space constraints.

Low maintenance: PMSM has a simple and robust design that requires minimal maintenance. The absence of brushes and commutators reduces the need for periodic maintenance, resulting in reduced downtime and lower maintenance costs.

High precision and accuracy: PMSM offers high levels of precision and accuracy in control applications. The motor's high speed and torque control capabilities enable it to achieve precise position control and speed regulation, making it suitable for use in applications such as robotics and automation.

High dynamic response: PMSM has a high dynamic response, meaning that it can respond quickly to changes in load and speed. The motor's ability to respond quickly to changes in control signals enables it to achieve high levels of performance in applications that require rapid and precise movement.

1.5.2. DISADVANTAGES

While PMSM (Permanent Magnet Synchronous Motor) has many advantages, it also has some disadvantages. Here are some of the disadvantages of PMSM:

High initial cost: PMSM can be more expensive than other types of motors due to the cost of the permanent magnets used in the rotor. This can make it challenging to justify the higher upfront costs for some applications.

Susceptibility to demagnetization: The permanent magnets in the rotor of PMSM are susceptible to demagnetization due to high temperatures or magnetic fields, which can affect the motor's performance and efficiency. This issue can be mitigated by using high-quality magnets and proper cooling systems.

Limited speed range: PMSM has a limited speed range compared to other types of motors. The motor's maximum speed is determined by the frequency of the AC power source and the number of poles in the stator. This limitation can be a disadvantage in some applications that require a wide speed range.

Complexity of control: PMSM requires complex control systems to achieve high levels of performance and efficiency. The control systems must be able to adjust the frequency and amplitude of the current supplied to the stator windings to control the speed and torque of the motor accurately.

Sensitivity to voltage variations: PMSM is sensitive to variations in voltage, which can affect its performance and efficiency. The voltage supplied to the motor must be closely regulated to ensure optimal operation.

1.5.3. APPLICATIONS

Electric vehicles: PMSMs are commonly used in electric vehicles due to their high efficiency and power density. Our optimization of the shape of the rotor magnet could potentially improve the performance of PMSMs used in electric vehicles, resulting in a longer range, faster acceleration, and improved overall performance.

Industrial applications: PMSMs are also commonly used in various industrial applications, such as pumps, compressors, and fans. By optimising the shape of the rotor magnet, we could potentially improve the efficiency and performance of PMSMs used in these applications, resulting in reduced energy consumption and cost savings.

Wind turbines: PMSMs are often used in wind turbines due to their high efficiency and low maintenance requirements. Our optimization of the shape of the rotor magnet could potentially improve the performance of PMSMs used in wind turbines, resulting in increased power output and improved overall efficiency.

Robotics: PMSMs are commonly used in robotics due to their high torque and precise control capabilities. By optimising the shape of the rotor magnet, you could potentially improve the performance and efficiency of PMSMs used in robotics applications, resulting in more precise movements and improved overall performance.

CHAPTER 2

PROPOSED MODEL

2.1. OBJECTIVES

- To design and simulate PMSM using FEA.
- To design an IPM PMSM motor for the specific EV Application.
- The power rating is fixed to 11KW as it is used in the existing EVs.
- To theoretically calculate the stator dimensions and slots based on the required design.
- To select the magnet shape and material of the Permanent magnet mounted on the Rotor .
- Verify the design and simulate to estimate the losses in the PMSM.
- To consider the factors affecting the losses and use one of the methods to reduce the losses.
- Obtain the final output results of the PMSM motor using finite element analysis.
- To analyse the future scope in the design of the PMSM motor.

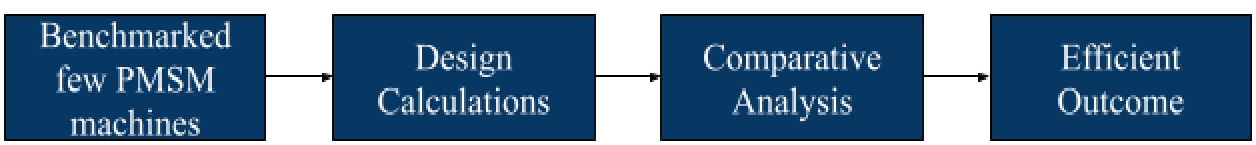
2.2. PROBLEM STATEMENT

The problem addressed in this project is the suboptimal PMSM performance used in electric three wheelers caused by losses, which leads to operational inefficiencies, noise, and vibration. While PMSMs are widely used in electric vehicles due to their high efficiency and torque density, there is still room for improvement in their design to achieve better performance, reduced losses, and increased efficiency. One specific aspect of the PMSM design that can be optimised is the thickness of the rotor magnets, which plays a critical role in determining the motor's torque output, efficiency, and flux distribution.

2.3. SOLUTION

The solution for optimising the rotor design in a PMSM for electric three-wheelers involves conducting a comparative analysis between the existing PMSM design and an optimised design with altered magnet thickness. The optimization process will involve a combination of analytical calculations and FEA simulations to obtain accurate data on the magnetic flux distribution in the motor and to evaluate the performance parameters of interest such as torque, efficiency, losses, flux, and flux distribution. The results will help to identify the optimal magnet thickness for the PMSM rotor that can provide the highest possible torque output, increased efficiency, reduced losses, and improved flux distribution. The optimised rotor design can help to improve the performance and efficiency of PMSMs, reduce energy consumption, and extend the range of electric three-wheelers, making them more practical and appealing for consumers.

2.4. PROCESS DIAGRAM



The project involved benchmarking several electric vehicles (EVs) and conducting design calculations to determine the most efficient outcome. The benchmarking process involved evaluating the performance of the EVs based on various parameters, such as range, efficiency, and power output.

After the benchmarking process, a comparative analysis was conducted to identify the most efficient EV based on the performance parameters. The comparative analysis involved evaluating the results of the design calculations for each EV and comparing them against each other.

Finally, based on the results of the comparative analysis, the most efficient outcome was determined. The efficient outcome was selected based on the performance parameters that were considered in the project, such as range, efficiency, and power output. The selected outcome was deemed to be the most efficient and practical for the given application. The findings of this project can be used to guide decision-making in the development and selection of EVs for various applications.

CHAPTER 3

PROJECT MANAGEMENT TOOLS

3.1. NEED ANALYSIS

Needs Analysis is a formal, systematic process of identifying and evaluating the need of the product for the customers. Needs are often referred to as "gaps," or the difference between the demand and supply of a product. In Project Management, need analysis work is undertaken before the project work begins, therefore it is said to be the project initiation phase.

- To propose a solution for optimising the rotor design in a PMSM for electric three-wheelers.
- To improve the performance and efficiency of PMSMs
- Reduce loss of Energy in the Machine
- To finalise the stator poles
- To select the suitable stator slots
- Appropriate selection of rotor's magnetic material

3.1.1. BULL DIAGRAM

A bull diagram is a simple tool that enables teams to clarify the needs of the project before making a decision. As the name suggests, the diagram is set up to look like a bull's face. The centre circle contains the product title , there are two oval-like structures acting as horns of the bull. The left oval specifies who will be using the product and the right oval specifies on what or where the product is going to act. The description box at the bottom which acts as a collar for the bull talks about the purpose of the product. The bull diagram of our product, to design an IPM PMSM Motor with reduced losses for EV Applications is shown.

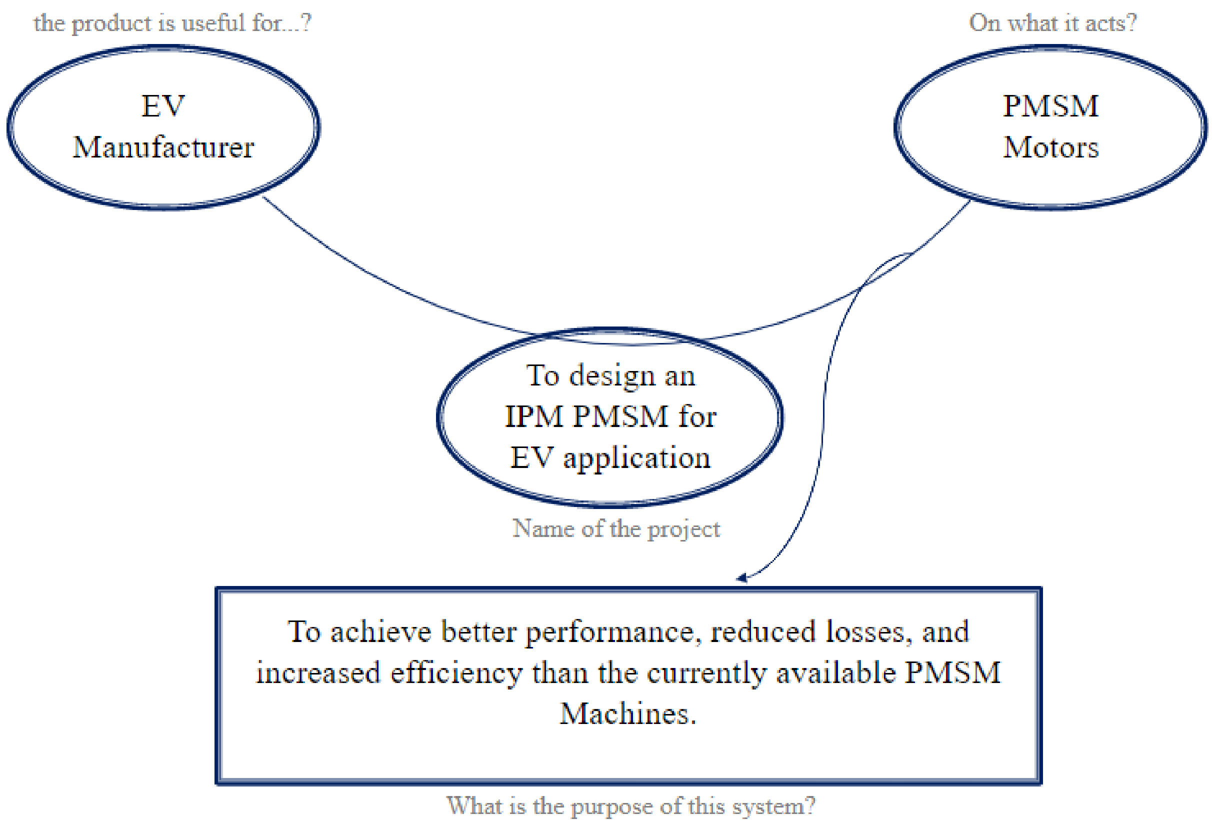


Figure 3.1 Bull Diagram

a) In the product we designed, the face of the bull is the title of our product which is to Design a IPM PMSM for EV Applications.
b) The left horn is the end users , in our case it is the EV three wheeler Manufacturers.
c) In the right horn we have specified the product on which it acts which is the currently existing PMSM Motor.
d) The main purpose of our project is to optimise the rotor design to

help improve the performance and efficiency of PMSMs, reduce energy consumption, and extend the range of electric three-wheelers, making them more practical and appealing for consumers.

3.2. FUNCTIONAL ANALYSIS

Functional analysis is the next step in the Systems Engineering process after setting goals and requirements. The functional analysis divides a system into smaller parts, called functional elements, which describe what we want each part to do. We do not include the how of the design or solution yet. At this point we don't want to limit the design choices because it might leave out the best answer. In later steps, we will identify alternatives, optimise them, and select the best ones to make up the complete system. The name Function comes from mathematical functions, which act on an input value and produce a different output value. Similarly, in the Systems Engineering method, functions transform a set of inputs into a set of outputs. The functional analysis includes all the service functions by defining assessment criteria. Level of each criteria, flexibility of the same as a table.

Table 3.1 Principal and Constraint functions

Principal Functions (the product links two external elements)	
PF1	To conduct a comparative analysis between the existing PMSM design and an optimised design with altered magnet thickness.
PF2	To optimise the rotor design to help improve the performance and efficiency of PMSMs
Constraint Functions (the product links one external element)	
CF1	To provide smooth function with the advancement

CF2	Achieving Maximum Flux Density
CF3	Designed based on the required application in this case for EV Three Wheelers.
CF4	Change in the dimension yields to increase in power density, Such as thickness of the magnet
CF5	The power supply is given to Motor from the battery through Inverter Circuitry
CF6	Improved efficiency at rated Speed.
CF7	Reduced Power Consumption
CF8	Industry will be benefited by the advancement in the motor

3.2.1. COMPONENTS OF OCTOPUS DIAGRAM

Octopus diagram as the name says the diagram is set up to look like an octopus. The main purpose of the Octopus diagram is to identify the interaction between the elements in the system and to justify their functions. Based on their functionalities, the octopus diagram is classified into two major sections.

▪ **Principle Function (PF):** Interaction of the product with elements of the Surroundings.

▪ **Constraint Function (CF):** Refers to the presents adoption or action of the product, in means of either the product, has to be adopted with an element or it acts on an element.

3.2.2. METHODOLOGY TO DRAW OCTOPUS DIAGRAM

- Place your product in the center of the diagram inside a circle that acts as the body of the octopus.
- The tentacles of the octopus will be the elements supporting the product and the curve lines are the interaction of elements.
- Write all the elements involved in the product in separate circles around the center.
- Identify the interactions between the elements and classify them as principle function and constraint function.
- Express the function in a sentence and put them up on a table.

3.2.3. OCTOPUS DIAGRAM

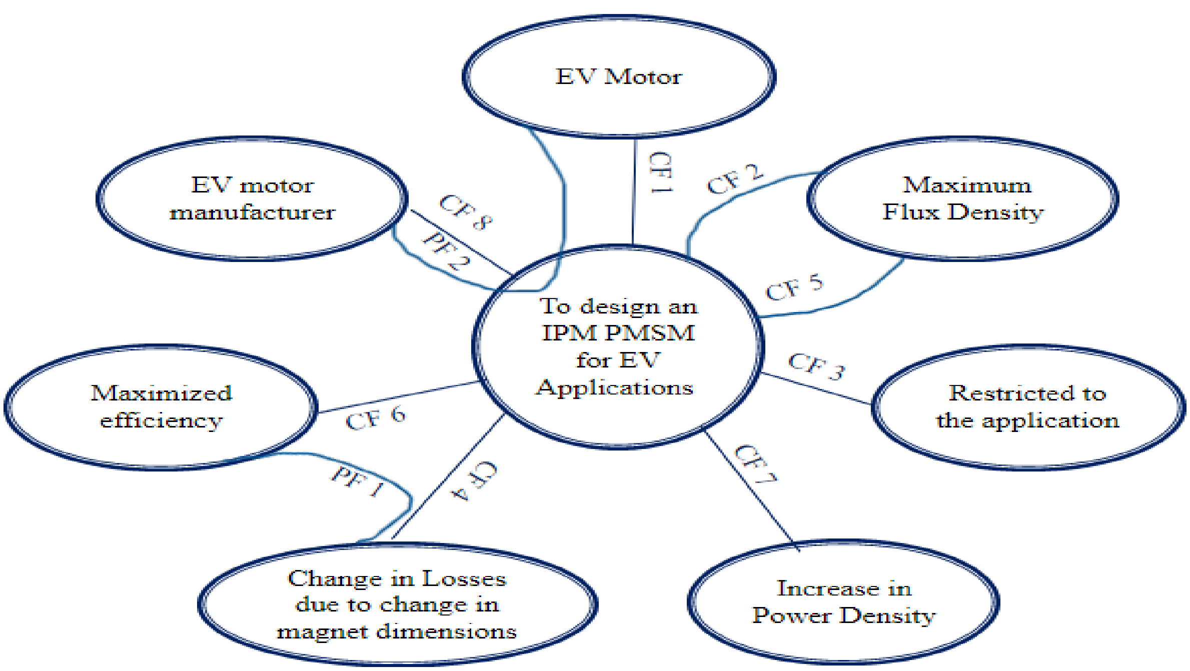


Figure 3.2 Octopus Diagram

Principal Functions

PF1 : To conduct a comparative analysis between the existing PMSM design and an optimised design with altered magnet thickness.

PF2 : To optimise the rotor design to help improve the performance and efficiency of PMSMs

Constraint Functions

CF1 : To provide smooth function with the advancement

CF2 : Achieving Maximum Flux Density

CF3 : Designed based on the required application in this case Electric Three Wheeler.

CF4 : Change in the dimension yields to increase in power density,
Such as thickness of the magnet

CF5 : The power supply is given to Motor from the battery through an Inverter Circuitry

CF6 : The efficiency is improved

CF7 : Reduced Power Consumption

CF8 : Industry will be benefited by the advancement in the motor

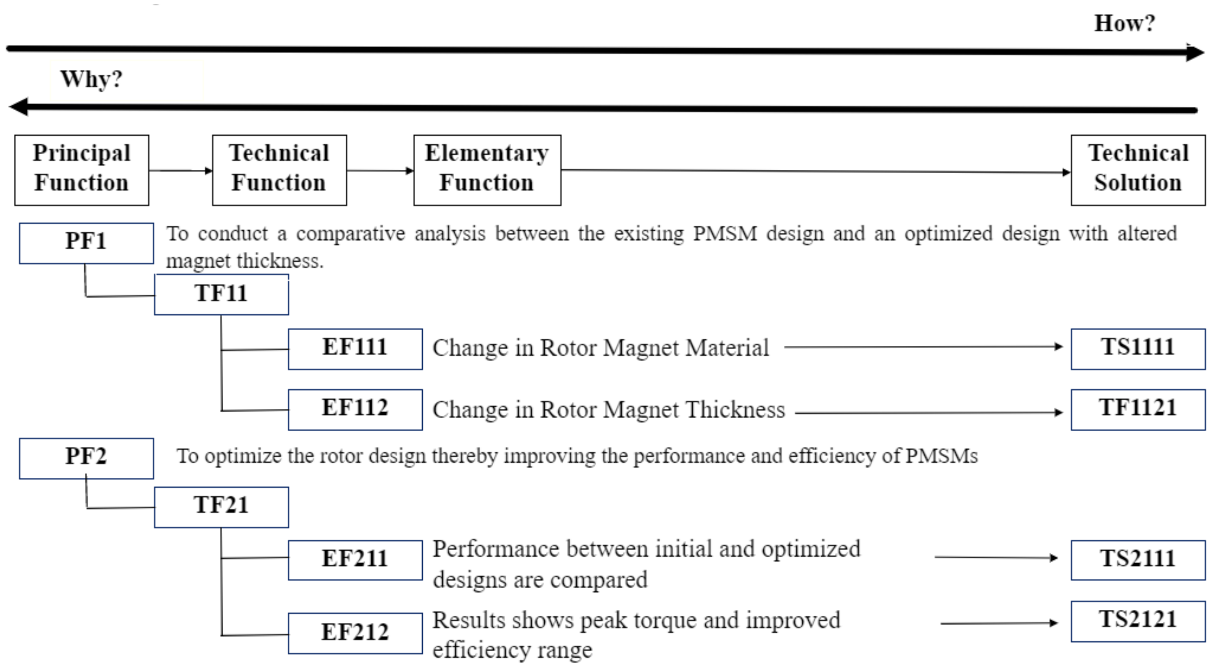
3.3. TECHNICAL ANALYSIS

Technical analysis represents study of the project to evaluate technical and engineering aspects when a project is being examined and formulated. It is a continuous process in the project appraisal system which determines the prerequisites for meaningful commissioning of the project.

3.3.1. FAST DIAGRAM

The Functional Analysis System Technique (FAST) diagram is a technique to develop a graphical representation showing the logical relationships between the functions of a project,product, process, or service based on the questions how? and why?

The main purpose of the FAST diagram is to represent the complex technology behind the product in a simple chart and to identify the interaction between the different functions.



3.4. RISK ANALYSIS

This tool has two main objectives:

- To list before starting the project what could make it go slower than expected
- To prepare actions to prevent them to appear or to treat

them efficiently

The methodology to make the risk analysis is listed below:

- Do a brainstorming to list all the possible risks which
- may cause a failure of the project
- Sum up all the data in a matrix
- Multiply the sum of both criteria (Likelihood and Consequence)
- Work in priority on those with highest mark
- Give actions to do in order to prevent the risks to happen
- Give actions to do if the risk happened to cure it

Table 3.2 Risk Analysis

Risk	Assessment of risk Likelihood criteria					Assessment of risk consequences criteria					Global Assessment
Names	Alfred	Andria	Benita	Bennet	Kirthika	Alfred	Andria	Benita	Bennet	Kirthika	
Technical research analysis	2	2	1	1	2	2	2	3	2	1	80
Deciding the functional specs of the motor	1	2	1	2	1	2	2	2	1	2	63
Bening able to understand and explore concepts	2	2	2	1	3	1	3	1	1	2	80
Working on the software and basics	3	2	2	2	2	1	1	2	1	1	66

3.5. GANTT CHART

Objective

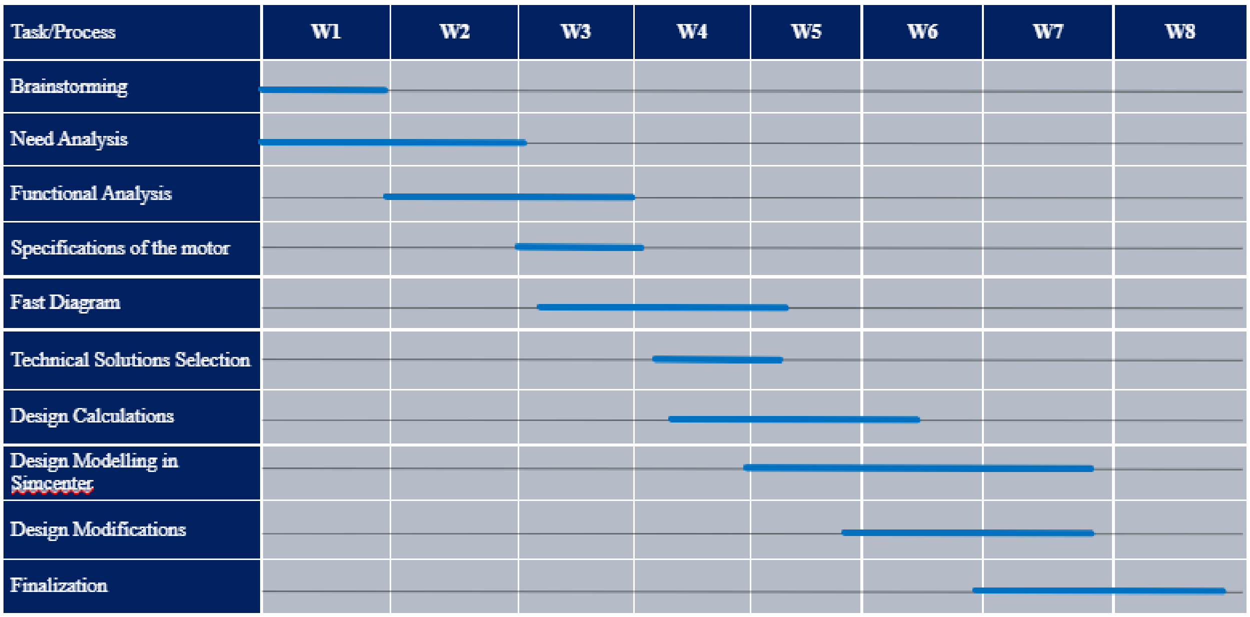
- Establishing the milestones of the project
- Display on a timeline the tasks
- Have a visual chart of the work done and yet to be completed

Methodology

- From the Pert chart get the order of the tasks
- Define the main milestones on a timeline

- Display the tasks on the timeline
- Make sure that the workload of the team is well split.

Table 3.3 Gantt Chart



CHAPTER 4

PROPOSED METHODOLOGY

4.1 DESIGN CALCULATION

We have designed a motor that has the following specifications and can be utilised for Electric Vehicles.

Table 4.1 Motor specifications

Rated Power	11 kW
Maximum Speed	1500 rpm
Peak Torque	90 Nm
Air Gap Length	0.5mm
Stator Slots	36
Rotor Poles	12
Supply Voltage	415 V
Magnetic Material	NdFeB
Magnet Thickness	4.25

The formula used to calculate the Stator diameter (D) and length(L):

The equation used to find the diameter and length

$$D^2L = Q/C_0N_s \text{ --------- } (1)$$

D − diameter of the inner stator

L − Length of the inner stator

Where Q is ;

$$Q \ = \ power\ rating\ /\ efficiency\ x\ Power\ factor$$ --------- (2)

$$N_s \ = \ 120\ f/P$$ ---------- (3)

Stator slots;

$$S_{ss} = \ \pi D/15$$ ---------- (4)

Where stator slot pitch can be in the range

$$Y_{ss} \ = \ 15\ to\ 25\ mm$$

$$S_{ss} \ = \ m\ x\ p\ x\ q$$

m $-$ number of poles

p $-$ number of phases

q $-$ slots/ pole / phase

Average flux density B_{avg}

$$B_{av} \ = \ P\ \phi/DL\pi$$ ------------ (5)

$$T_{ph} = \ E_s/\ 4.44\ f\ \phi_m\ K_{wm}$$ ------------ (6)

Where;

T_{ph} - is the torque developed per phase.

4.2. OPTIMIZATION DESIGN TECHNIQUES

In high-performance applications the torque smoothness is critical. By doing a comparative analysis in the thickness of the permanent magnets used we can arrive at a more efficient PMSM motor with the appropriate design specifications. Our project is based on the optimization of the Inner Rotor configuration by changing the thickness of the magnets in the Permanent Magnet Synchronous Motor. Radial magnetization pattern can be applied to the permanent magnet motors, motors are in different sizes and shapes for the different applications. The shape of the permanent magnet used is the curved type permanent magnet.

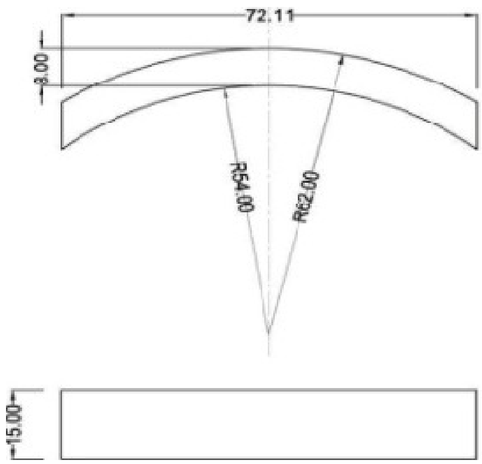


Figure 4.1 Top and front view of curved magnet

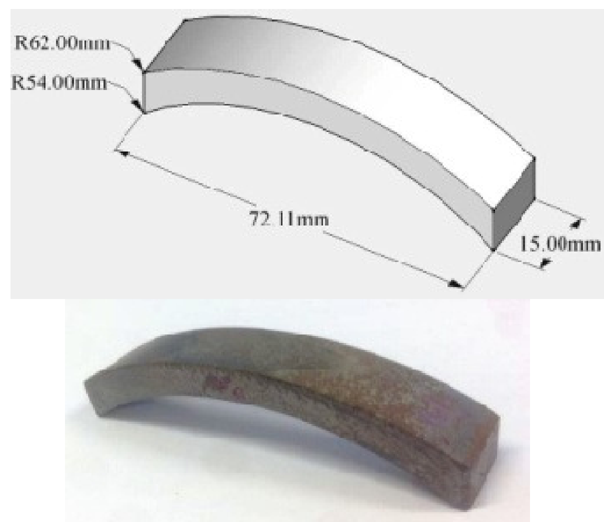


Figure 4.2 Dimensions of curved magnet

4.3. COMPARISON OF MOTORS AND MAGNET SHAPE

We initially did a comparative study on the different motors which are used in the EV industry and the different magnet shapes used to analyse the best cogging torque output and efficiency and the results are tabulated below.

Table 4.2 Motor Comparison

Motor parameters	**Prius (2010)**	**Camri (2007)**	**Prius (2004)**	**Accord**
Stator outer diameter(mm)	264	264	269	315.5

Stator inner diameter(mm)	161.9	161.9	161.93	232
Length(mm)	50.8	60.7	84	40.1
No. of slots	48	48	48	24
Material	REF M330 35A	REF M330 35A	REF M330 35A	REF M330 35A
Conductor material	REF Copper	REF Copper	REF Copper	REF Copper
Air gap length(mm)	$7.5e^{-1}$	$7.0e^{-1}$	$7.3e^{-1}$	1.0
Rotor outer diameter(mm)	160.4	160.5	160.47	188.0
Rotor inner diameter(mm)	110	105	111	40.1
Length(mm)	50.8	60.7	84.0	76
No. of poles	8	8	8	8
Material	REF M330 35A	REF M330 35A	REF M330 35A	REF M330 35A
Magnetic material	NdFeB 1320_1400	NdFeB 1320_1400	NdFeB 1320_1400	NdFeB 1320_1400

Table 4.3 Magnetic material: NdFeB 38/15, Stator shape: parallel tooth

Magnet shape	**Cogging torque**
Rectangular	More ripples
Variable orientation 2 layers	Less ripples
Variable orientation 3 layers	Less ripples
Angled barrier 4 layers	Ripples in negative

Lateral	Ripples in negative
Curved	Less ripples
Inset lateral	Perfect sine wave
Angled barrier	More ripples
V shaped barrier 2 layers	Ripples in negative
Variable orientation	Ripples in negative
Embedded variable	Ripples in negative
Embedded variable 2 layers	Ripples in negative

Table 4.4 Magnetic material: NdFeB 38/23, Stator shape: parallel tooth

Magnet shape	**Cogging torque**
Lateral	Ripples in negative
Curved	Less ripples
Inset lateral magnets	Withheld
Angled barrier	Ripples in negative
Angled barrier 2 layers	Ripples in negative
Angled barrier 4 layers	Ripples in negative
V shaped barrier 2 layers	Ripples in negative
Variable orientation	Ripples in negative
Variable orientation 3 layers	Less ripples
Embedded variable	Ripples in negative
Embedded variable 2 layers	Ripples in negative
Rectangular	Ripples in negative

Table 4.5 Magnetic material: NdFeB 38/23, Stator shape: parallel

Magnet shape	**Cogging torque**
Lateral	Perfect sine wave
Curved	Less ripples
Inset lateral	Sine wave with light ripples
Angled barrier 4 layers	Ripples in negative
V shaped barrier 2 layers	Sine wave with light ripples
Variable orientation	Ripples in negative
Variable orientation 3 layers	Sine wave with light ripples
Embedded orientation	Less ripples
Embedded orientation 3 layers	Perfect sine wave
Rectangular	Ripples in negative

Table 4.6 Magnetic material: NdFeB 38/15, Stator shape: parallel

Magnet shape	**Cogging torque**
Rectangular	More ripples
Embedded 3 layers	Perfect sine wave
Embedded variable orientation	More ripples
Variable orientation 3 layers	Sine wave with light ripples
Variable orientation	Ripples in negative
V shaped barrier 2 layers	Less ripples
Angled barrier 4 layers	Ripples in negative
Angled barrier	Less ripples
Inset lateral	Less ripples

Curved	More ripples
Lateral	Less ripples

4.4. LOSSES AND EFFICIENCY

The various losses in Synchronous motors are :

Stator copper losses

The stator loss consists of copper loss and iron loss. Copper loss is the loss due to the current going through the armature windings. The copper loss consists of I 2R loss and stray load loss. The I^2R losses are given by

$$P_{cu} = m_1 I^2 R \text{ ------------ (7)}$$

where m_1 is the number of phases, I is the armature current, and R is the dc armature resistance. The I^2R loss can be significant when large current flows through the conductor with large Ohmic resistance.The copper loss is temperature dependent, so the copper loss is calculated at the expected copper temperature. The copper I^2R loss increases when copper temperature increases due to increased winding resistance, while the copper stray load loss reduces with increased temperature. In addition to the analytical method described above, loss due to proximity and skin effects can also be simulated based on transient time-stepping. However, this method is very time consuming especially when multiple strands are used.

Rotor copper losses

The rotor loss generated by induced eddy current in the steel shaft and permanent magnets is not significant compared with the total machine loss. However, removing the heat from the rotor to ensure reasonable operating temperatures of its components is more difficult than removing the heat from the stator. Thus, an accurate prediction of rotor loss becomes important especially at high speed. The major causes of the rotor eddy current loss can be categorised into the following three groups: a no-load rotor eddy current loss caused by the existence of slots, b on-load rotor eddy current loss induced by the harmonics of windings' magnetomotive force MMF, which is also called space harmonics, and c on-load rotor eddy current loss induced by the time harmonics of the phase currents due to PWM. Loss due to eddy current, in general, can be expressed by

$$P = \int_V \sigma E^2 dV = \int_V J^2/\sigma dV \text{ ------------ } (8)$$

where is the material conductivity, E is the electric field, J is the eddy current density, and V is the volume of the material. There are several methods to reduce rotor eddy current losses. Reducing the slot opening and increasing the magnetic gap between rotor and stator can reduce no-load rotor loss. Increasing the number of slots per pole and using fractional winding can reduce rotor loss caused by the space harmonics of the armature winding. Increasing the switching frequency and using external line inductors can reduce rotor loss caused by time harmonics of the phase currents. Since rotor loss caused by time harmonics is dominant in most applications, increasing the switching frequency and using external line inductance to reduce current THD is a very effective way to reduce rotor loss.

Stator iron losses

Iron loss produced in a magnetic material operating in an alternating magnetising field is generally separated into two components: hysteresis loss and eddy current loss. Hysteresis loss is due to a form of intermolecular friction when a varying magnetic field is applied to the magnetic material. The loss per cycle is proportional to the area enclosed by the hysteresis loop on the B-H characteristics of the material. The hysteresis loss increases with the maximum magnetic field The empirical formula expressing the hysteresis loss per unit volume $P_h\,(W/m^3)$in terms of the maximum flux density((B) (T)) and frequency f (Hz) was developed by Steinmetz as follows:

$$P_h = \eta B^n f \text{ ------------ (9)}$$

where η is a material constant and n is an exponent, which has typical values between 1.8 and 2.2, depending on the lamination material.

Friction and windage losses

Windage loss is heat generated in the fluid due to the relative motion shearing of the fluid that flows between the rotor and stator. Windage loss, depending on various gases at various operating conditions, as used in high speed machines can be very high, contributing to overall machine inefficiency. The windage loss generation is a function of shaft rotational speed and fluid properties such as temperature, pressure, density, and temperature gradients at stator and rotor walls. The windage loss generated in the clearance between a rotating cylinder and a stationary cylinder with homogenous laminar flow no axial flow can be estimated.Theoretical relations and experimental validation taking into account the combination of axial flow and rotational flow, in the case of cooling media passing through the gap, can be included to obtain a better estimate. Also, surface roughness of the stator tooth and rotor surface affects windage loss and must be taken into account.

Efficiency

The calculation of losses except additional losses has been explained earlier.

output

Efficiency at full load η $= output / (output + losses)$ ------------ (10)

Additional Losses

The additional losses include

(i) additional copper losses

(ii) additional iron losses.

With a sinusoidal voltage impressed across the terminals of the motor, the additional copper losses are due, in part, to the higher order mm harmonics and in part to skin effect. The additional losses owing to higher order mm harmonics occur mainly in windings of squirrel cage rotor. These additional copper losses may be decreased by

(i) chording the stator winding,

(ii) skewing the rotor,

(iii) having a proper slot combination

The skin effect phenomenon is observed in stator and rotor windings especially in squirrel cage machines. Here the effect may be used for improving starting characteristics of motors with a cage rotor.

However, during normal operating conditions the frequency of the current in the rotor does not exceed about 3 Hz or so and therefore this skin effect is practically absent.

The additional losses in iron consist of

(i) pulsation losses

(ii) surface losses.

The pulsation losses are caused by direct axis pulsation of magnetic flux due to variation of permeance caused by continuous change in mutual positions of rotor and stator teeth during rotation of rotor.

Pole face loss

A ripple is superimposed on the flux density wave owing to the presence of slots on the armature surface. The ripple moves with respect to poles and induces eddy currents in the pole faces. The pole face loss depends upon the slot opening, air gap length, number of slots and the speed of the machine.

The poles should be laminated in order to reduce the pole face loss. In practice, either the poles are laminated or when made of solid iron, the pole shoes are laminated. In turbo-generators the rotor is solid but owing to a large air gap, the pole face losses are small

In synchronous machines pole face loss varies between 25 to 70 per cent of total iron loss.

Stray load loss

Stray load loss occurs due to stray fields which appear when the machine is loaded. For example, the armature mm wave contains higher harmonics of the order 5, 7, 11, 13. These higher harmonic mmfs cause higher harmonic fields which travel over the pole face and induce eddy currents there and thus increase the iron loss at load.Additional losses at load may be caused by armature leakage flux in the overhang region surrounding the iron portions and the end plates.

Actually stray field loss may appear in the pole faces, core and overhang and end plates.This loss is very difficult to calculate and yet they may be comparable with whole of the stator I^2R loss.

Excitation loss

Field copper loss = I_f^2 × resistance field winding. ------------ (11)

Besides I^2R loss there is brush contact losses on the slip rings. The following voltage drops may be assumed in brushes :

for carbon and graphite brushes- 1 V and for brushes containing metal- 0.3 V.

If the pilot and the main exciters are driven from the same shaft, the losses in the exciters must be taken into account.

Friction and windage loss

This loss consists of bearing friction and rotor windage loss. This loss depends upon the type of construction, speed and rating of the machine and varies between 0.2 to 0.8 percent of kVA rating. The higher values are for high speed and high rating machines. With hydrogen cooling the total friction loss reduces to 0.3 to 0.4 per cent of KVA.

4.5. SUPPLEMENTARY DESIGN CONSIDERATIONS

Following text presents some relevant discussions or supplementary design considerations about permanent magnet dc motors.

Number of poles - Total volume of magnet is inversely proportional to the number of poles. This logic is in favour of a large number of poles but if lap winding is used, one brush is required for each pole which may result in undesirable cost excitation. On the other hand if wave winding is used, only two brushes are required regardless of the number of poles. Also, the flux reversal in the armature is directly proportional to the number of poles. Thus, for higher speed machines, an undesirable iron loss in ironless may result from increasing the number of poles. Thus, as a general guideline, the number of poles greater than two should be considered for larger motors of relatively low speed. For smaller motors of relatively higher speed, two poles are generally satisfactory.

Brushes - Brush manufacturers should be consulted for recommended grades and sizes best suited for a particular motor. In PM de motors, brush shift should be approached with considerable caution as flux shift in the ceramic magnet will be found to be almost negligible. Introduction of arbitrary brush shifts very well results in shifting them away from the electrical neutral axis and causing improper operation. Also brush shifts increase the demagnetisation effect.

Thermal consideration - There are two primary reasons for thermal failure in motors the first one is increase of resistance of motor winding due to increase in temperature and the second one is the inability of the motor to dissipate the heat generated. The first reason produces lower motor torque while the second problem creates insulation failure. Better quality insulation is recommended to prevent the motor from insulation failure. In order to reduce the first problem, it is recommended to design the motor with higher ventilation arrangements.

Gearing - When it is necessary to multiply the torque available from or motor or it is required to increase or decrease the output speed, a gear system is needed to be coupled with the motor. There are three types of gears in use: spur gears, helical gears and worm gears.

Bearing - Usually a ball bearing or a journal bearing is to be used. Bell bearings are better than journal bearings in every respect except cost and noise. The most serious defect of journal bearings is high starting torque. It also requires higher lubrication.

Lubrication - The most important function of any lubricant is to provide a film of oil between rotating and stationary surfaces so that metal to metal contact never occurs. The second basic function of lubricant is to carry away heat generated for friction. The third function of the lubricant is to act as a seal against foreign particles entering the bearing.There are three principle types of lubricants in use namely oil, dry film lubricants and grease.

4.6. EFFECT OF MAGNETIC THICKNESS ON MAGNETIC FIELD

Due to the fact that the electromagnetic performance highly depends on the magnetic field distributions, it is necessary to firstly analyse the effect of the magnet thickness on magnetic fields. In this section, both radial and tangential components of PM and armature fields are investigated. It is worth noting that both PM and armature fields are affected by saturation significantly. Therefore, the frozen permeability method is used here to calculate these two fields under rated working conditions.

4.6.1. PARAMETRIC APPROACH METHOD

In this method, permanent magnet thickness is defined as a variable. According to the numerically calculated standard motor magnet thickness, initial magnet thickness value is defined. The initial magnet thickness value was calculated as (insert mm value of magnet) in the study. After defining the initial value of the permanent magnet thickness, the solution range and the solution steps for the variables are defined . Solution range and the solution step are directly proportional with the sensitivity of the solution. The solution range of the magnet thickness in the study is between 3.25mm to 4.25mm .

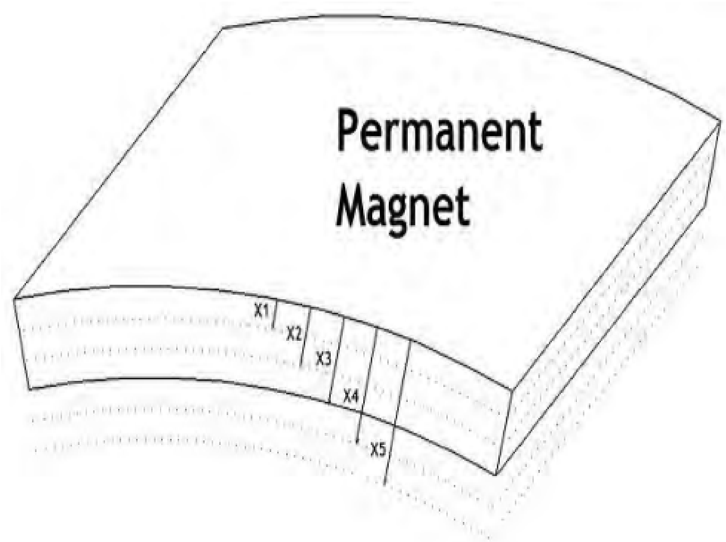


Figure 4.3 thickness of curved magnet

4.6.2. COMPARATIVE ANALYSIS

Permanent Magnet Synchronous Motors (PMSMs) are electric motors that use permanent magnets on the rotor to provide a magnetic field that interacts with the stator's rotating magnetic field. The thickness of the magnets used in a PMSM motor can play a significant role in its efficiency and torque.

In general, increasing the thickness of the magnets in a PMSM motor can increase its torque density. This is because a thicker magnet can provide a stronger magnetic field, which results in a higher torque output. However, the effect of magnet thickness on efficiency is more complex.

Thicker magnets can increase the cogging torque of the motor, which is the torque produced by the interaction of the rotor and stator magnetic fields when there is no current flowing in the motor. Cogging torque can lead to energy losses and reduce the efficiency of the motor. Therefore, it is essential to optimise the magnet thickness to balance the trade-off between torque and efficiency.

Additionally, thicker magnets can also increase the weight and cost of the motor. Therefore, it is crucial to consider the overall system requirements when selecting the optimal magnet thickness for a PMSM motor.

In summary, the thickness of the magnets used in a PMSM motor can impact its torque density and efficiency, but it is essential to balance these factors against other system requirements such as weight and cost.

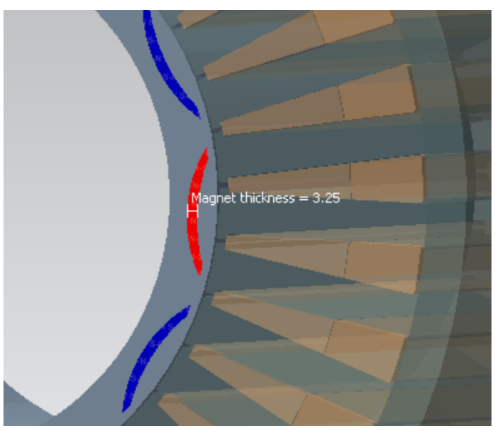


Figure 4.4 Curved magnet of 3.25mm   Figure 4.5 Curved magnet of 4.25mm

Rated Speed versus Magnet Thickness

The effect of magnet thickness on the speed of a Permanent Magnet Synchronous Motor (PMSM) is relatively small and indirect. In general, the thickness of the magnets in a PMSM motor primarily affects its torque and efficiency, which can impact the motor's performance at different speeds.

At low speeds, the motor's torque is the primary factor that limits its performance. Increasing the thickness of the magnets in a PMSM motor can increase its torque density, which can improve its low-speed performance. This is because a thicker magnet can provide a stronger magnetic field, which results in a higher torque output. However, at high speeds, the motor's performance is limited by its efficiency, as energy losses in the motor increase with increasing speed.

Rated Torque versus Magnet Thickness:

The thickness of the magnets in a Permanent Magnet Synchronous Motor (PMSM) can have a significant impact on its rated torque, which is the maximum torque that the motor can produce continuously without overheating or damaging its components.

In general, increasing the thickness of the magnets in a PMSM motor can increase its torque density, which can result in a higher rated torque. This is because a thicker magnet can provide a stronger magnetic field, which results in a higher torque output. However, the effect of magnet thickness on rated torque depends on several other factors, including the design of the motor, the materials used, and the manufacturing process.

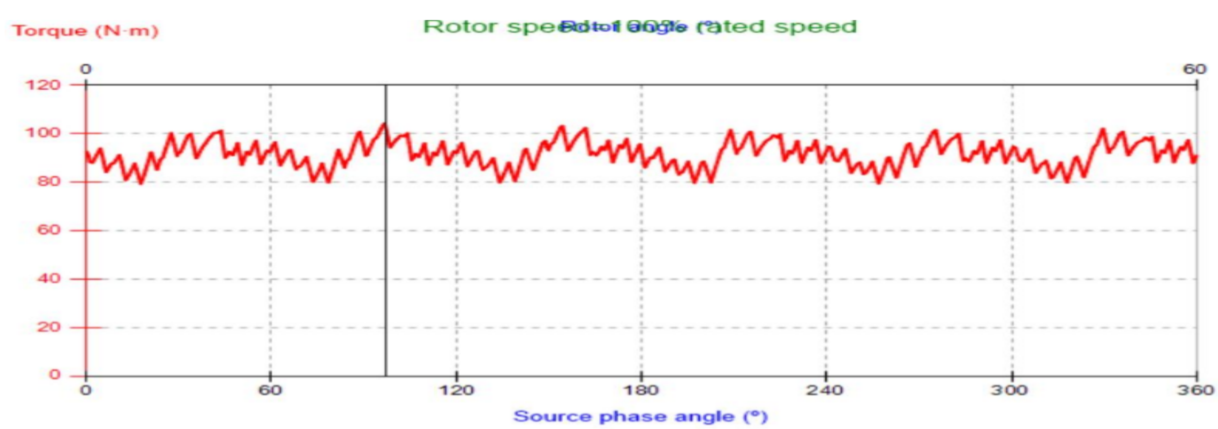


Figure 4.6 Torque of 4.25mm magnet

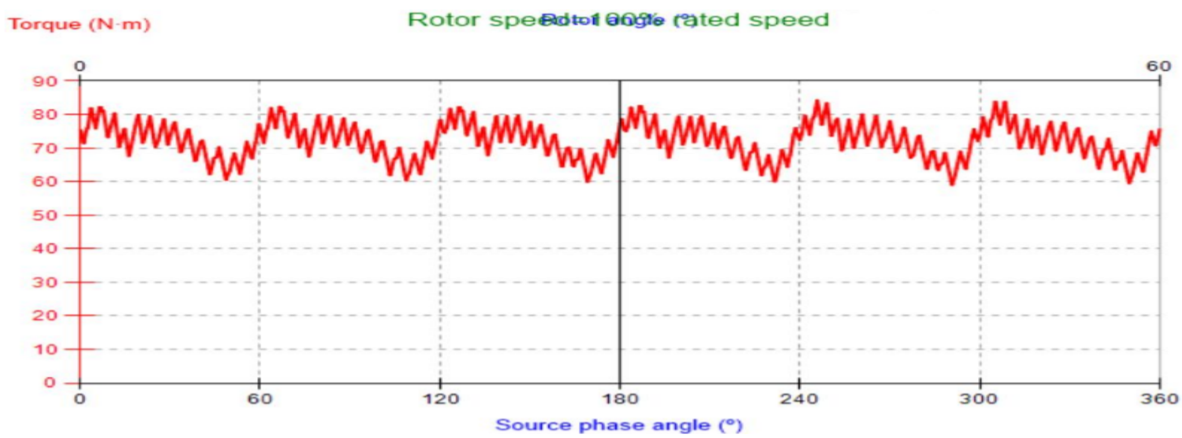


Figure 4.7 Torque of 3.25mm magnet

Efficiency versus Magnet Thickness:

The thickness of the magnets in a Permanent Magnet Synchronous Motor (PMSM) can have a significant impact on its efficiency. However, the effect of magnet thickness on efficiency is not straightforward, and it depends on several factors, including the design of the motor, the materials used, and the operating conditions. Thicker magnets can also improve the motor's efficiency by increasing its torque density.

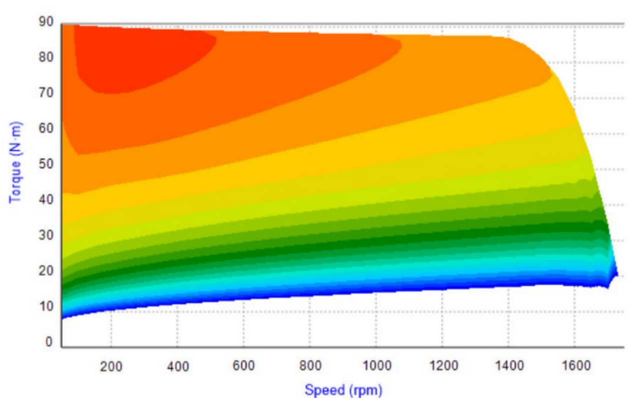


Figure 4.8 Efficiency of 4.25mm magnet

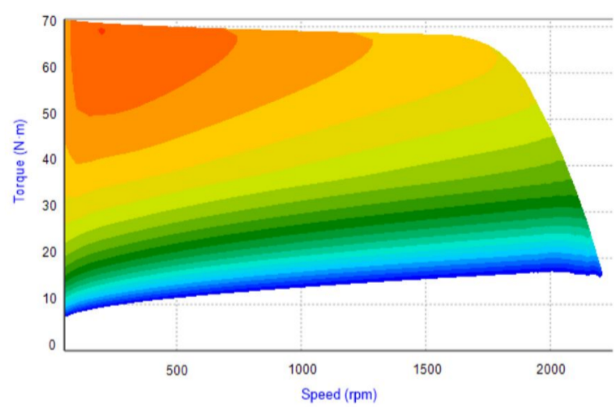


Figure 4.9 Efficiency of 3.25mm magnet

Losses versus Magnet Thickness:

The thickness of the magnets in a Permanent Magnet Synchronous Motor (PMSM) can have a significant impact on its losses, which are the energy losses that occur due to various factors such as resistive losses, eddy current losses, and hysteresis losses. The effect of magnet thickness on losses depends on several factors, including the design of the motor, the materials used, and the operating conditions. A higher torque output can reduce the motor's losses due to current flow, resulting in improved efficiency.

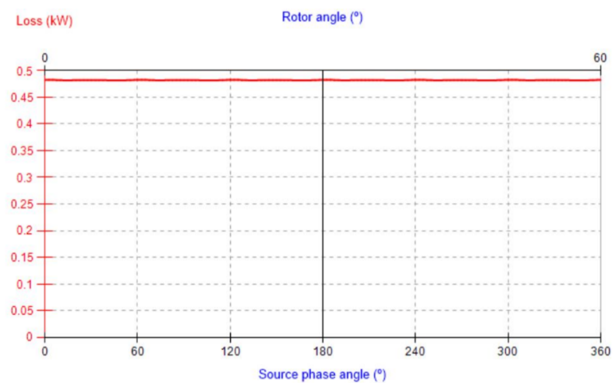


Figure 4.10 Losses in 3.25mm magnet

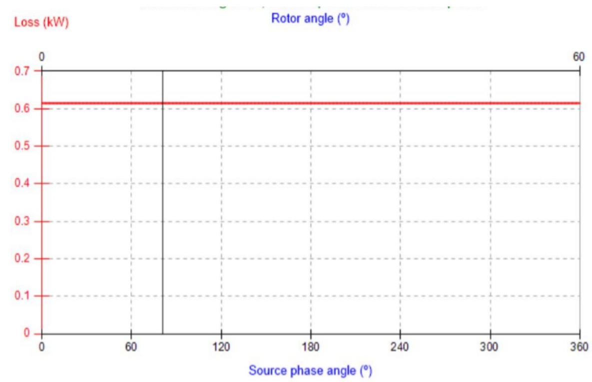


Figure 4.11 Losses in 4.25mm magnet

Therefore, the optimal magnet thickness for a PMSM motor depends on the specific requirements of the application, including the desired efficiency, losses, torque output, and other factors such as weight, size, and cost. The design of a PMSM motor is a complex optimization problem that involves balancing multiple factors to achieve the best overall performance for the application. In general, the optimal magnet thickness for a PMSM motor depends on the specific requirements of the application and the operating conditions.

The above stated results are tabulated for a better understanding. From these characteristics we have seen the advantages and disadvantages of the lower and higher values of magnet thickness to motor performance.

Table 4.7 Comparative Analysis

Magnet Thickness	Rated Speed	Peak Torque	Efficiency	Losses
3.25mm	1800 rpm	82.6 Nm	92-93	0.486
4.25mm	1500 rpm	110 Nm	93-94	0.621

We can analyse that if the magnet's thickness is reduced, it results in low production of torque. Since torque is inversely proportional to speed, speed due to increased magnet's thickness is increased. Efficiency is also decreased but the losses due to magnet's thickness is less.We can also observe that if the magnet's thickness is increased, it results in high production of torque. Since torque is inversely proportional to speed, speed due to increased magnet's thickness is decreased. Efficiency is also increased but the losses due to magnet's thickness is high. Finally, the optimum magnet thickness can be chosen according to the desired cost and motor performance.

4.7. ROLE OF FLUX DISTRIBUTION

In this project, the role of flux distribution is crucial in assessing the performance of the permanent magnet synchronous motor (PMSM) in electric three-wheelers. Flux distribution refers to how the magnetic flux generated by the rotor magnets is distributed within the motor. It plays a significant role in determining the motor's efficiency, torque output, and overall performance. A well-optimised flux distribution is important for several reasons:

1. Reduced losses: Proper flux distribution helps minimise losses within the motor, such as eddy current losses and hysteresis losses. By controlling and optimising the flux distribution, these losses can be minimised, resulting in improved motor efficiency and reduced energy consumption.

2. Increased torque output: The distribution of magnetic flux directly impacts the motor's torque output. An optimised flux distribution ensures that the magnetic field is evenly distributed across the stator, resulting in a higher torque output. This is essential for electric three-wheelers, as it determines the motor's ability to accelerate, climb gradients, and handle varying loads efficiently.

3. Improved efficiency: The flux distribution directly affects the motor's efficiency. By optimising the flux distribution, magnetic losses can be minimised, leading to improved efficiency and reduced heat generation within the motor. This results in a more energy-efficient motor that can help extend the range and improve the overall performance of electric three-wheelers.

4. Uniform rotor heating: Proper flux distribution helps ensure uniform heating of the rotor. This is important for the longevity and reliability of the motor. By maintaining an even flux distribution, hot spots and localised overheating can be minimised, contributing to the overall durability and lifespan of the motor.

Therefore, analysing and optimising the flux distribution is a critical aspect. Through simulations, analytical calculations, and design modifications, ensuring an optimal flux distribution within the PMSM can significantly improve the motor's efficiency, torque output, and overall performance in electric three-wheelers.

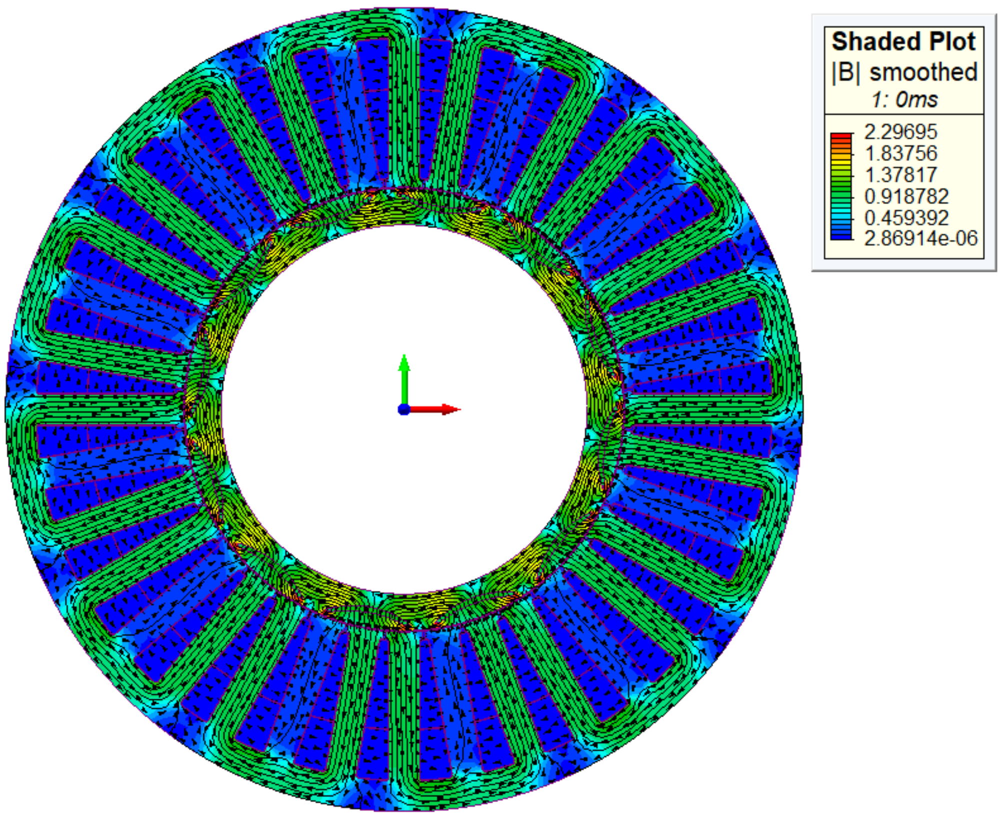


Figure 4.12 Flux distribution path for curved magnets

CHAPTER 5

ELECTRIFYING THE ROAD: UNRAVELLING THE ELECTRIC POWER TRAIN AND BATTERY MECHANICS

5.1. ELECTRIC POWERTRAIN

The power for the electric motor PMSM is converted from the DC Battery to AC via DC to DC converter and Inverter. As the accelerator is pressed, a signal is sent to the controller. The Controller adjusts the speed of the vehicle by changing the frequency of the AC power from the inverter to the motor.

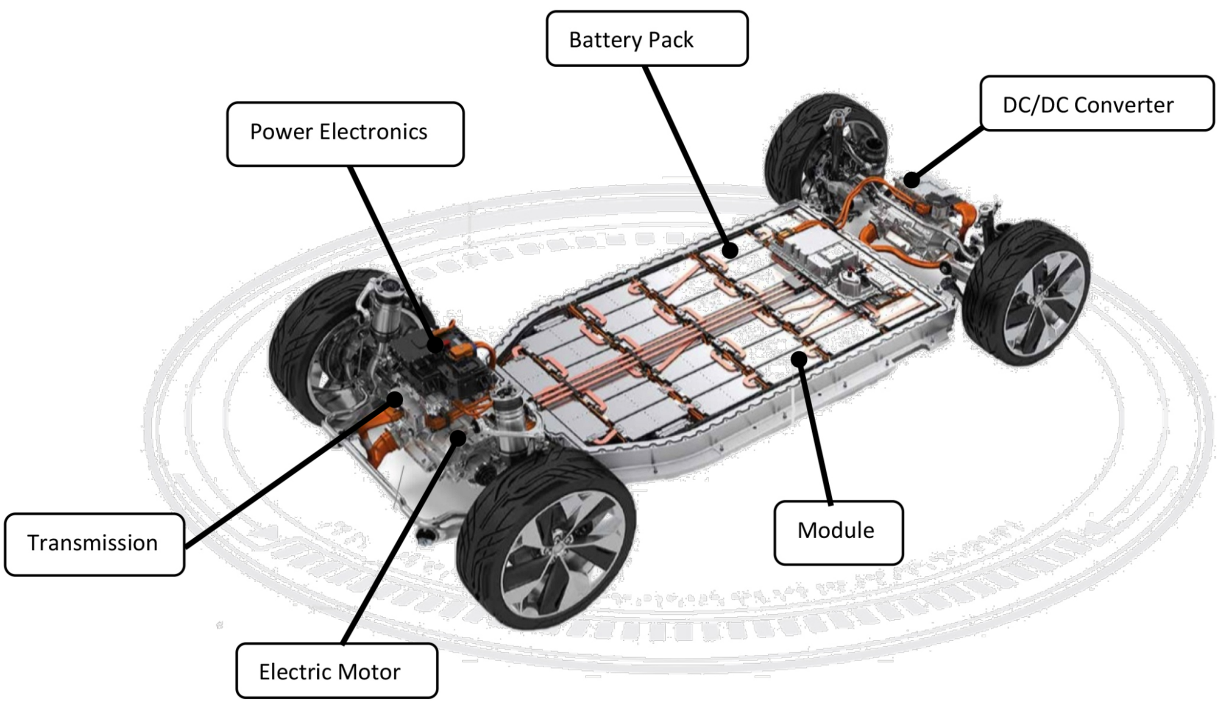


Figure 5.1 Electrical Powertrain Design

With the controller set, the inverter then sends a certain amount of electrical energy to the motor (according to the depth of pressure on the pedal) Electric motor converts electrical energy into mechanical energy. Rotation of the motor rotor rotates the transmission so the wheels turn and then the car moves. If the brakes are pressed, or the electric car is decelerating, the motor becomes an alternator and produces power, which is sent back to the battery.

5.2. BATTERY OPERATED VEHICLE

There are several types of batteries that are commonly used in electric vehicles.

Lithium-ion batteries: These are the most common type of battery used in electric vehicles. They are lightweight and have a high energy density, which means they can store a lot of energy in a relatively small space.

Nickel-metal hydride (NiMH) batteries: These batteries are commonly used in hybrid vehicles, as they are not as efficient as lithium-ion batteries, but are still more efficient than traditional lead-acid batteries. They are also less expensive than lithium-ion batteries.

Lead-acid batteries: These are the oldest and most well-known type of battery. They are heavy and have a low energy density, but they are also the least expensive.

Solid-state batteries: These are a newer type of battery that use a solid electrolyte instead of a liquid or gel electrolyte. They have the potential to be safer and more energy-dense than lithium-ion batteries, but they are still in the experimental stage and not yet widely used in electric vehicles.

Zinc-air batteries: These batteries use zinc and oxygen to produce electricity, and are lightweight and have a high energy density. However, they are not yet widely used in electric vehicles and are still being developed.

Overall, lithium-ion batteries are currently the most popular and widely used type of battery in electric vehicles due to their high energy density and relative affordability.

Figure 5.2 Power Supply for Electrical Drive

5.3. VECTOR CONTROLLED PMSM-DRIVE OPERATION IN AN ELECTRIC VEHICLE

A traditional vector control drive for Permanent Magnet Synchronous Motors is the PMSM Drive. A closed-loop speed control based on the vector control approach is present in this drive. A closed-loop design with speed feedback is offered. A complete infinite speed range, including full torque at zero speed, is provided by the drive because of its feedback, which enables it to track the precise rotor position. The operation of PMSM motors requires position sensors in the rotor shaft when operated without damper winding. The ones most commonly used for motors are encoders and resolvers. The speed control loop outputs the reference electromagnetic torque of the machine taken from an external source can be an analog signal and encoder feedback, or a serial command from a feedback device. These PM drives use motor data and current measurements to calculate rotor position; the digital signal processor (DSP) calculations are quite accurate. During every sampling interval, the three-phase AC system dependent on time and speed is transformed into a rotating two-coordinate system in which every current is expressed and controlled as the sum of two vectors.

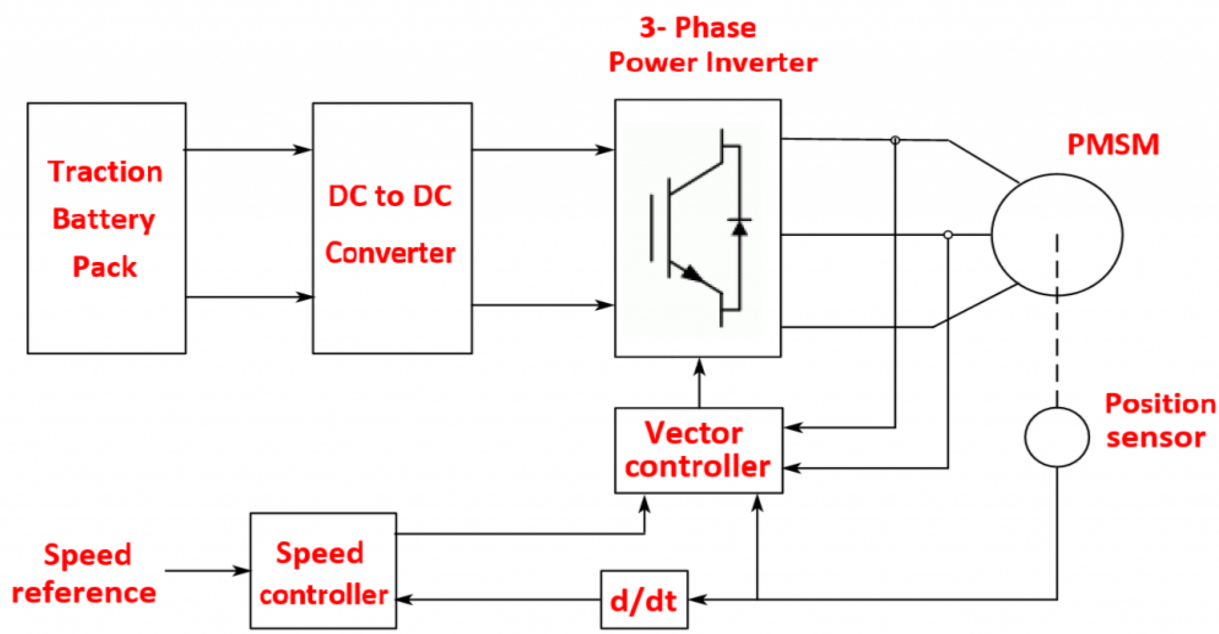


Figure 5.3 Vector control Block diagram

Based on a vector control technique, the reference direct and quadrature (dq) components of the stator current corresponding to the demanded torque are obtained. A hysteresis-band current controller is then utilised to acquire the necessary gate signals for the inverter using the reference dq components of the stator current. This drive's quick dynamic reaction is its key benefit over scalar-controlled drives. Through decoupling (stator flux orientation) control, which enables the torque and flux to be controlled independently, the machine's inherent coupling effect between the two is managed. However, the implementation of this drive necessitates fast processors or DSPs due to the complexity of its computation.

5.4. MATLAB SIMULATION OF THE ELECTRICAL DRIVE WITH A VECTOR CONTROLLED DRIVE OPERATION:

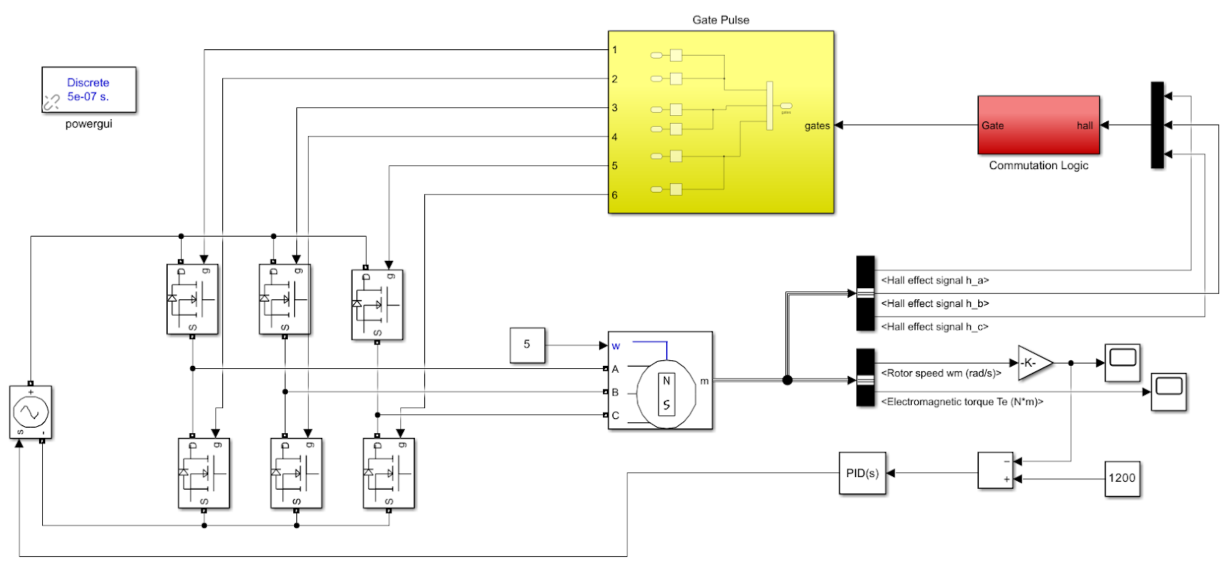


Figure 5.4 Matlab simulation for Electrical Drive

The Electrical Powertrain with an input supply of 48V, a vector controlled inverter controller is connected to the PMSM Drive and the output characteristics of the motor such as the Electromagnetic Torque and Speed of the machine is analysed. A closed loop system with the Position Sensor is used to identify the Rotor angle. The input is given to a PID controller which is designed to compare the input with the preset reference. The error signal obtained from the PID Controlled is given to the triggering circuit with modified firing angle to obtain the desired speed of the motor.

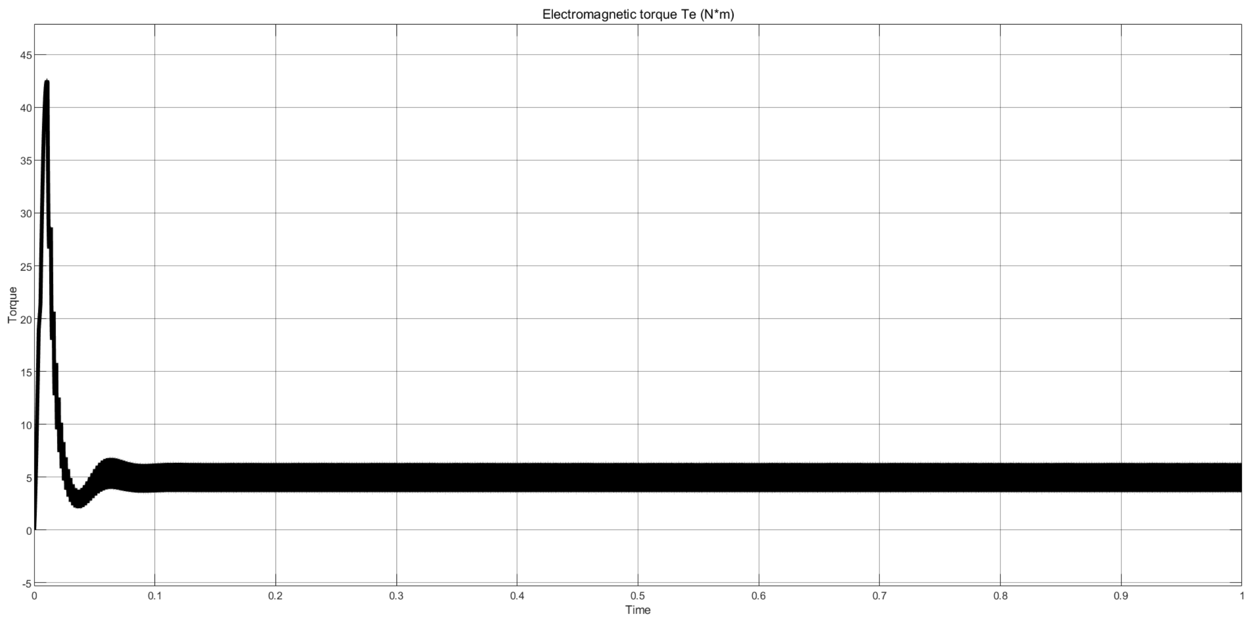


Figure 5.5 Maximum Torque

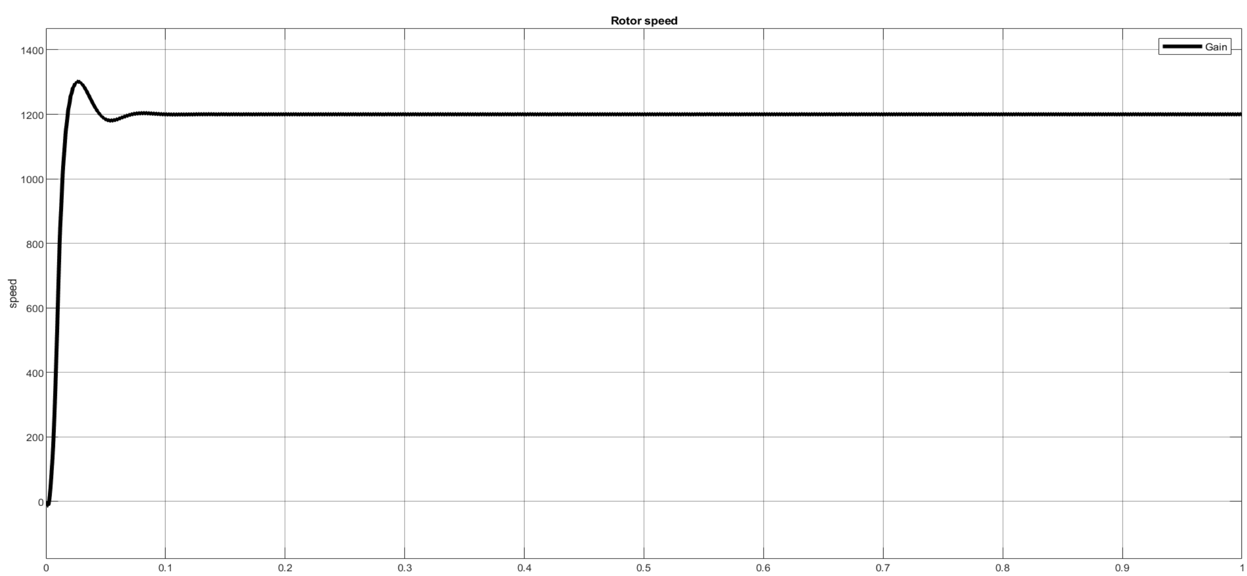


Figure 5.6 Speed output for the Drive

CHAPTER 6

CONCLUSION

The conclusion of this project is based on the analysis of the effect of altering the magnet thickness on various performance parameters of a permanent magnet synchronous motor (PMSM) used in electric three-wheelers. The objective of the project was to optimise the rotor design of the PMSM to achieve higher torque output, increased efficiency, reduced losses, and improved flux distribution.

The optimization process involved a combination of analytical calculations and finite element analysis (FEA) simulations to obtain accurate data on the magnetic flux distribution in the motor and to evaluate the performance parameters of interest. The results of the analysis showed that the optimised rotor design with altered magnet thickness can significantly improve the performance of PMSMs.

The first performance parameter considered in this study was torque output. The results showed that increasing the magnet thickness can lead to a significant increase in the motor's torque output. This is due to the increased magnetic field strength generated by the thicker magnets. The optimal magnet thickness was determined to be the point where further increases in magnet thickness did not result in a significant increase in torque output.

The second performance parameter considered was motor efficiency. The results showed that increasing the magnet thickness can also lead to an increase in the motor's efficiency. This is due to the reduced magnetic losses and improved flux distribution resulting from the thicker magnets. The optimal magnet thickness was determined to be the point where further increases in magnet thickness did not result in a significant increase in motor efficiency.

The third performance parameter considered was motor losses. The results showed that increasing the magnet thickness can lead to a reduction in the motor's losses, specifically eddy current losses. This is due to the reduced magnetic flux density and improved flux distribution resulting from the thicker magnets. The optimal magnet thickness was determined to be the point where further increases in magnet thickness did not result in a significant reduction in motor losses.

The fourth performance parameter considered was flux and flux distribution. The results showed that altering the magnet thickness can have a significant impact on the magnetic flux density and distribution in the motor. The optimal magnet thickness was determined to be the point where the flux density and distribution were maximised while minimising magnetic losses.

Overall, the optimised rotor design with altered magnet thickness can provide significant improvements in the performance of PMSMs used in electric three-wheelers. The results of this project are highly relevant to the electric vehicle industry, as they can help to improve the performance and efficiency of PMSMs, reduce energy consumption, and extend the range of electric three-wheelers, making them more practical and appealing for consumers.

In summary, the findings of this project provide valuable insights into the design and optimization of PMSMs for electric three-wheelers and offer a foundation for further research and development in this field. The optimised rotor design can be used by engineers, researchers, and manufacturers to design and develop more efficient and sustainable electric vehicle technologies.

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