V. Nandagopal/Afr.J.Bio.Sc. 6(14) (2024) 5845-5854 ISSN: 2663-2187

https://doi.org/10.33472/AFJBS.6.14.2024.5845-5854

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper Open Access

Analysis of PMDC and Synchronous RM on Electric Motorcycle

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Article Info

Volume 6, Issue 14, August 2024

Received: 03 June 2024

Accepted: 04 July 2024

Published: 20 August 2024

doi: 10.33472/AFJBS.6.14.2024.5845-5854

ABSTRACT:

This research investigates the relative investigation of Permanent Magnet DC (PMDC) then Synchronous Reluctance Motor (Syn.RM) within the realm of electric motorcycles. The imperative for the growth of e vehicles arises from the environmental concerns associated with conventional vehicles. Currently, Permanent Magnet DC (PMDC) motors are widely employed in electric vehicles. However, the reliance on permanent magnet materials for torque generation in PMDC motors contributes to higher costs.In response to this limitation, the Synchronous Reluctance Motor (Syn.RM) has emerged as an alternative propulsion system for electric vehicles, as it operates without the need for permanent magnets. Syn.RMs are characterized by their durability, cost-effectiveness, and high efficiency. Moreover, these motors are capable of operating at exceptionally high speeds. In contrast, conventional motors exhibit drawbacks such as poor efficiency, low power factor, and suboptimal torque density, primarily due to low saliency indicated by a low ratio of Ldm/Lqm. This research centers on contrasting two motors based on factors such as torque, flux distribution type, flux density, material composition, and output power. The performance of the motors is assessed through calculations facilitated by software and a simulation model employing the Finite Element Analysis (FEA) Method. The outcomes reveal that the extreme torque achievable with PMDC is 13.18 Nm, whereas for Syn.RM, it is 11.1 Nm. Additionally, the study findings indicate that the material weight essential for PMDC is 5.03 kg, which is lighter compared to the Synchronous Reluctance motor, weighing 4.27 kg.

Keywords: Permanent Magnet DC, Synchronous Reluctance Motor (Syn.RM), electric vehicles, Finite Element Analysis, flux distribution, material composition.

1. Introduction

The stator functions as the external structure of the PMDC motor, comprising its housing. Magnets are affixed to the inner side of the stator in a configuration where the North and South poles of the magnets alternate, facing the armature. In addition to containing the magnets, the stator serves as a pathway with low reluctance for the return of magnetic flux. To account for potential magnet power loss, an additional field coil is incorporated for compensation. The armature, which constitutes the mobile element of the PMDC motor, is comprised of winding, core, and commutator, connecting to the motor's output shaft. In contrast to some other motors where the rotor creates its magnetic field through a DC power source or induction, in PMDC motors, the rotor is simply made up of a ferromagnetic metal.An electric motor variant, such as the reluctance motor, incorporates a ferromagnetic rotor devoid of windings, yet capable of inducing non-permanent magnetic poles. Torque generation in this motor occurs through magnetic reluctance. This type of motor is individually excited, featuring a non-symmetrical rotor. An early 21st century, the utilization of this motor was limited due to challenges in design and control. However, advancements in design tools, theory, and embedded systems offer solutions to overcome these limitations.
The Syn. RM stands out as an alternating current (AC) motor celebrated for its simplicity and remarkable efficiency. Its operation revolves around the principle of reluctance, a key property in magnetic circuits. The term "synchronous" characterizes the motor's capability to run at a speed directly correlated to the provided frequency, ensuring its rotation stays synchronized with the power supply frequency.The fundamental concept underlying a synchronous reluctance motor is based on the tendency of a magnetic object to migrate from a region characterized by low magnetic permeability to one with high magnetic permeability. This behaviour is referred to as 'reluctance.' Analogous to the movement of an electrical charge from high resistance to low resistance in an electrical circuit, the rotor in the motor is crafted to establish zones of both high and low magnetic permeability.
The speed-voltage relationship in a PMDC motor can be elucidated through its equivalent circuit, resembling a DC shunt motor, but distinguished by the field being supplied by a permanent magnet [1]. The speed of a PMDC motor is modifiable within a range both below and above its nominal speed. A common approach for speed regulation entails modifying the input voltage to the motor. Numerous investigations have delved into techniques for managing the speed of PMDC motors, such as the utilization of a single-phase matrix converter (SPMC) for AC-DC power supply control [2]. This can be attributed to their advantages, including a broad constant power speed range and high torque density. Their efficiency and power density outperform those of induction machines and closely align with permanent magnet machines [2], [3]. In the present context, there is significant attention on the efficiency and cost of electrical machines. An illustrative application of electric machines is found in electric vehicles (EVs). The imperative for EVs arises from the growing concern over air pollution associated with conventional vehicles, prompting researchers and technicians to focus on developing technologies to enhance the efficiency and power capabilities of electric vehicles. Researchers emphasize the need to improve the efficiency of all these constituent parts that contribute to the performance of electric vehicles. The strategic selection of an optimal motor design becomes a focal point in efforts to boost the general competence of electric vehicles [7]. A magnet of PMSM typically comprise rare earth materials such as Neodymium, which are not only expensive but also susceptible to core losses.

Topographic Anatomy of PMDC and Syn. RM

In the Permanent Magnet DC (PMDC) motor scenario, the armature is situated within the magnetic field produced by permanent magnets embedded in the stator. Subsequently, the

armature undergoes rotation in response to the generated force. Comprising multiple conductors, each conductor experiences a force that is then translated into torque, facilitating the rotation of the armature. As the armature rotates, the spatial relationship between the stators and the armature diminishes due to the torque generated by the magnetic field. This positional change can reverse the torque every 90 degrees of rotation. To sustain the torque exerted on the rotor, a commutator affixed to the rotor shaft of the PMDC motor is employed. The commutator activates the current supply to the stator.This ensures the consistent maintenance of a 90-degree angle between two fields. As the current flow is periodically switched among windings during rotor rotation, the current within each stator winding alternates at a frequency corresponding to the number of motor magnetic poles and the rotational speed.
In the modern reluctance motor, the rotor is configured with iron laminations arranged axially and separated by non-magnetic material. The motor's performance closely resembles that of an induction machine, but its efficiency surpasses that of an induction motor due to the nonappearance of copper loss in the rotating part. The motor stands out for its simplicity, cost-effectiveness, and robust construction. Reluctance motors are particularly favored for their ability to provide exceptionally high-power density at a lower cost, making them suitable for various applications. However, notable drawbacks include high torque ripple at lower speeds and the generation of noise due to torque fluctuations. The stator of this motor predominantly features salient electromagnet poles, akin to a Brushless DC (BLDC) motor.

Design specification for Electric Vehicle and Motor
A. Overview About PMDC Motor Specifications
The mechanical design of Permanent magnet DC (PMDC) is given as follows:

TABLE I. Geometric factor for PMDC

Factors	Value	Unit
Stator pole count (SP)	4	-
Magnet Arc (ED)	140	mm
Magnet Segments	1	mm
Back Iron Thickness	5	mm
Slot Number	20	-
Tooth Width	7	mm
Slot Depth	18	mm
Tooth Tip Angle	30	mm
Armature Diameter	110	mm
Shaft Dia	25	mm

TABLE II. Winding factor for PMDC

Factors	Value	Unit
Turns	50	Turn
Throw	5	-
Winding type	Lap	-
Path Pattern Type	Upper/Lower	-
Wire Type	AWG	-
Wire Size	AWG 23	-

Tables I and II display the parameter constraints specifications established based on the motor's intended application. This motor is intended to function as the main momentum system for the electric two-wheeler.

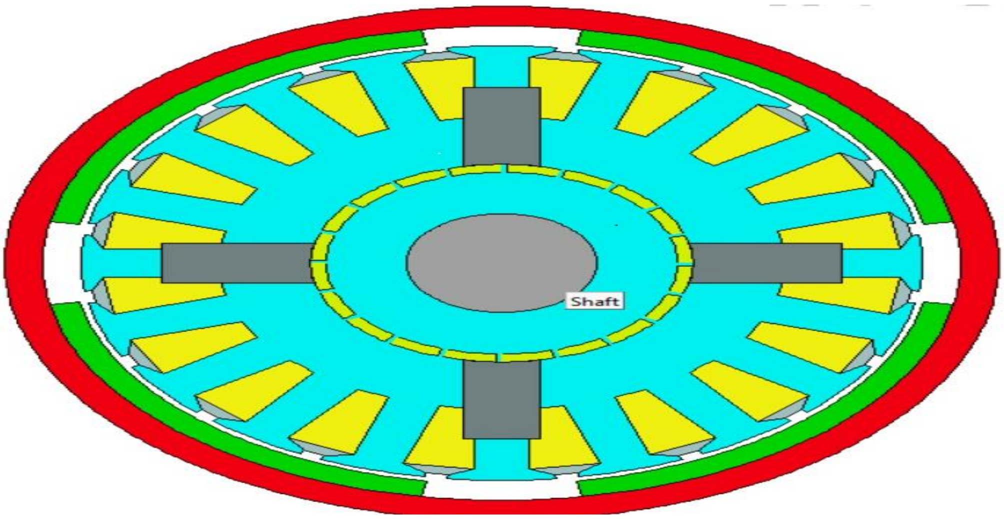

Fig.1 Dimensional View of PMDC motor

B. Overview About Syn. Reluctance Motor Specifications

TABLE III. Geometric factor for Syn. Reluctance Motor

Factors	Value	Unit
Number of slots.	12	-
Stator Lamination Diameter	130	mm
Stator Bore	80	mm
Tooth Width	9	mm
Slot Depth	18	-
Tooth Width	7	mm
Tooth Tip Angle	30	mm
Armature Diameter	110	mm
Shaft Dia	25	mm
Pole Number	4	-
Notch Arc Outer [ED]	20	mm

TABLE IV. Winding factor for Syn.Reluctance Motor

Factors	Value	Unit
Number of turns	4	Turn
Throw	3	-
Winding type	Lap	-
Path Pattern Type	Upper/Lower	-
Wire Type	AWG	-
Wire Size	AWG 23	-

TABLE V. Materials Data of PMDC and Syn.Reluctance Motor

Factors	Material	Resistivity in Ohm-m	Density in Kg/m^3	Weight in Kg
Stator Lamination	M350-50A	$4.4 * 10^{-7}$	7650	1.311
Armature Winding	Copper (Pure)	$1.724 * 10^{-8}$	8933	0.4161
Rotor Lamination	M350-50A	$4.4 *10^{-7}$	7650	2.544

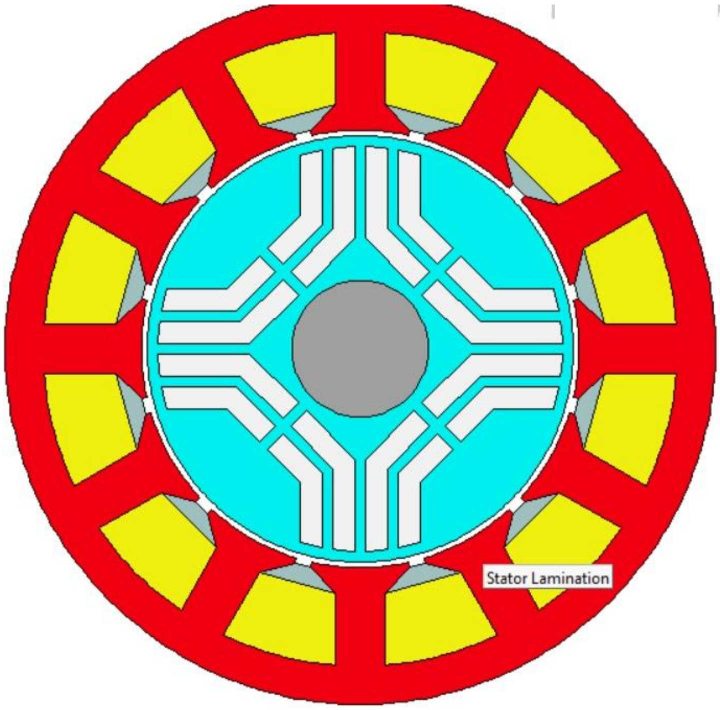

Fig.2.Dimensional View of Synchronous Reluctance motor

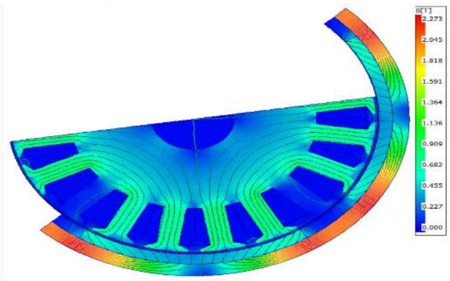

Fig. 3. Magnetic flux pattern Of PMDC

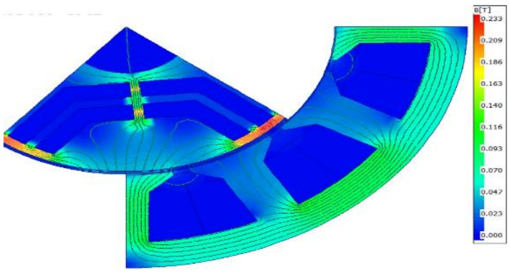

Fig. 4. Magnetic flux pattern of Syn.Reluctance Motor

The size of the motor is influenced by geometric dimension parameters, which must be carefully considered in the planning phase to ensure that the motor design aligns with the size requirements for an electric motorcycle. For both the stator and rotor laminations, the material M350-50A was selected for its low rated current, contributing to energy and cost savings by minimizing copper loss [8].

Examining figures 2 and 3, it is evident that PMDC exhibits the highest magnetic flux density value at 2.27 T, while Syn.RM registers at 0.233 T. Additionally, the flux distribution in PMDC appears more uneven compared to the focused distribution in Syn.RM, concentrating on a single point.

C. Flux Densities

The design of a propulsion motor is significantly influenced by the air gap flux density. A greater air gap flux is typically associated with smaller motor sizes, leading to a higher torque rating for the motor output. Consequently, this requires higher iron content in the lamination, leading to a decrease in the No. of slots(S) and turns (T) in the stator winding. In comparison between PMDC and Syn. Reluctance Motor, the air gap parameters are higher in PMDC, as indicated in Table VI and VII. Furthermore, the BH value is also greater in PMDC, as illustrated in figures 3 and 4.

TABLE VI. Flux Density Factors of PMDC

(AFD)- Airgap flux density (mean) and Peak	0.2782 wb/m^2 and 0.6226 wb/m^2
(SBIFD) Stator Back Iron Flux Density (peak)	2.335 wb/m^2
(RT) Rotor Tooth FD (peak)	1.243 wb/m^2
(RTT)Rotor Tooth Tip FD (peak)	1.408 wb/m^2
(RBI) Rotor Back Iron FD (peak)	0.46 wb/m^2

TABLE VII. Flux Density Factors of Syn.Reluctance Motor

(AFD)- Airgap flux density (mean) and Peak	0.2675 wb/m^2 and 0.5184 wb/m^2
Stator Tooth Flux Density (peak)	0.1208 wb/m^2
Stator Tooth Tip Flux Density (peak)	0.8479 wb/m^2
Stator Back Iron Flux Density (peak)	0.1252 wb/m^2
Rotor Back Iron Flux Density (peak)	0.8265 wb/m^2

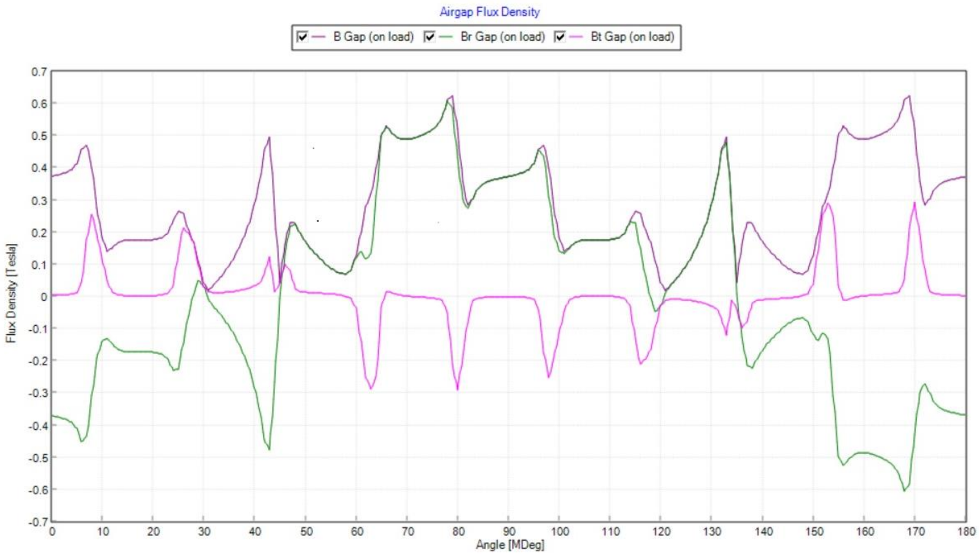

Fig.5 FD in Air gap for PMDC Motor

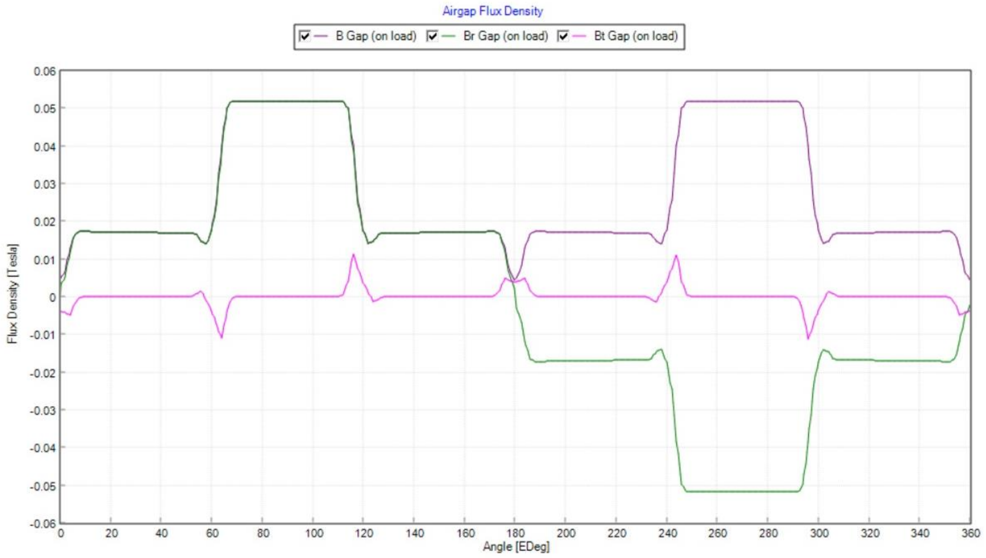

Fig.6 FD in Air gap for Syn.Reluctance Motor

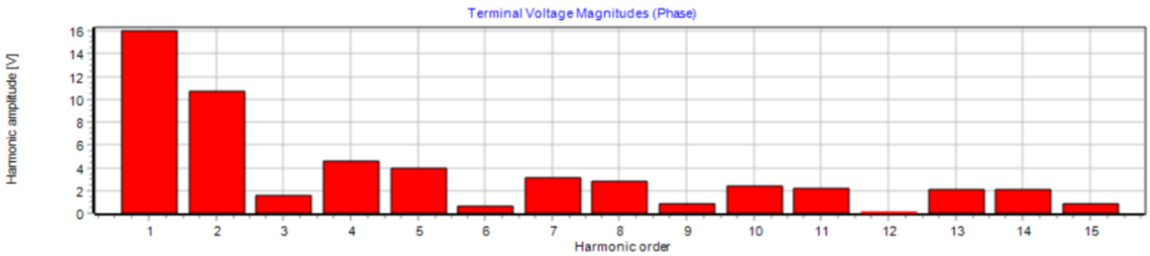

Fig.7 Harmonic order in PMDC

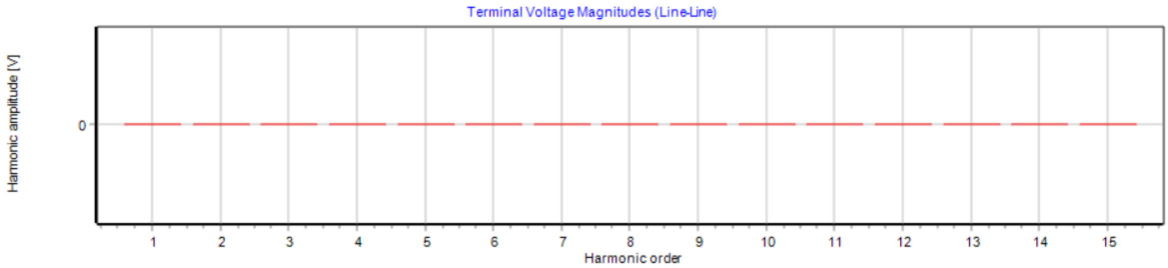

Fig.8 Harmonic order in Syn.Reluctance Motor

The harmonic order analysis of PMDC and Syn. Reluctance Motor was conducted using software. The first and second-order harmonics are prominent in the PMDC motor, whereas they are minimal in the Syn. Reluctance Motor, as depicted in figures 7 and 8.

2. Conclusion

A comprehensive investigation was undertaken to compare the performance of two motor types, namely PMDC and Syn. RM, in the framework of electric two wheeler. The analysis revealed that the torque generated by PMDC is marginally higher than that of Syn. Reluctance Motor. However, Syn. Reluctance Motor exhibits a extra uniform delivery of magnetic attractive flux across the motor segment compared to PMDC. In Syn. Reluctance Motor, the magnetic FD attains the situation peak value, reaching 0.23 T. The AGFD within PMDC motor remains higher average value than Syn. Reluctance Motor, attributed to the nature of PMDC employing permanent magnets, while Syn. Reluctance Motor lacks magnets. The study's outcomes further indicate that the material weight required for Syn. Reluctance Motor is 4.27 kg, lighter than PMDC, which weighs 5.03 kg.In summary, the study concludes that Syn. Reluctance Motor is lighter, produces slightly lower torque output, and exhibits lower harmonic orders than PMDC motor. However, it necessitates an additional driver circuit in electric motorcycle applications for optimal performance.

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