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Development of a Prototype Coreless PMDC Motor, Performance Characterization and Comparative Analysis against Cored PMDC Motor

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Abstract:
In the present study, a prototype of coreless PMDC motor was successfully developed, tested for its performance characteristics and analyzed for its performance comparison with a cored PMDC motor of the same power rating. The comparative performance analysis showed that the coreless PMDC motor has a wider torque and speed range as compared to cored PMDC motor for the same input current range. The rotor speed range in coreless PMDC motor was found lesser than that of the cored PMDC motor for the same Voltage range. The slope of Torque vs rotor speed graph for coreless PMDC motor was significantly lesser as compared to that of cored PMDC motor. Also the torque level was much higher for coreless PMDC motor in comparison with that of cored PMDC motor. The cost analysis of the prototype showed that the manufacturing cost is significantly competitive since the laminated steel core is absent in the coreless PMDC motor.

Keywords: *coreless motor, permanent magnet motors, prototype development, performance characterization, comparative analysis, cost analysis*

1. Introduction

Generally, in DC motors, the stator and rotor assemblies include laminated steel core. It is well reported in the literature that the DC motors with axial magnetic flux demonstrate improved steady state and transient performance [1, 2, 3, 5, 6]. Advancements in the motor technology revealed a new feature - Using high energy permanent magnets, DC motors can be fabricated without the steel cores [4, 5]. This advanced coreless PMDC motor has less mass and works with increased efficiency at the same power and shaft torque. Also, a coreless PMDC motor demonstrates, at zero current state, the absence of any normal force among the stator and rotor. Due to this, the torque pulsations are practically eliminated [7]. Rapid acceleration and deceleration are other major advantages of coreless PMDC motor due to its low mass [8,9]. Iron and hysteresis losses are reduced in coreless PMDC motors leading to a better and lower time constant. Performance wise they have better speed verses torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation, higher speed ranges, and rugged construction in comparison to cored DC Motors [10] (Kim et al. 1999). Recently, coreless DC motors are manufactured for servo and industrial electromechanical drives [3] and also for solar powered electrical vehicles [7]. The aim of this study is to develop the prototype of a coreless PMDC motor, to test for its performance characteristics, to compare its performance with that of a cored PMDC motor of the same power rating and evaluation of this emerging technology.

2. Design and Development of Prototype

The constructional features of the developed prototype and the test set-up is shown in Figure 1. The design data of the prototype is given in Table 1. The winding of the coils was done manually. The center shaft and the support structure for the windings were prepared using acrylic material. Friction-less ball bearings were fixed on both ends of the center shaft which were held over V shaped wooden stand. Copper commutator and spring loaded carbon brushes were used to power the prototype coreless PMDC motor. Cylindrical shaped permanent magnets were used as field magnets.

Figure 1: Constructional features of the prototype coreless DC motor and the test set-up

Max Input Voltage	28 V DC
Max Input Current	8 Ampere
Speed range	400-1200 rpm
Number of rotor coils	4
Max input power	224 W
Number of turns per coil	150
Coil wire	Insulated copper
Wire diameter	24 SWG (0.559mm)
Length of coil winding	140mm
Width of coil winding	50mm
Rotor outer diameter	95mm
Shaft diameter	20mm
Commutator diameter	20mm
Dimensions of carbon brushes	15mm x 5mm
Diameter of permanent ferrite magnet	120mm
Thickness of permanent ferrite magnet	20mm
Air gap	1mm
Cooling system	Natural
Class of insulation	F
Frictionless Bearing (Qty. 2)	SKF 6304-2Z

Table 1: Design data of the prototype coreless DC motor

3. Testing Methodology

The developed prototype of coreless PMDC motor was tested for evaluating the following performance parameters; a) Variation of speed (RPM) vs. variation in input current, b) Variation of rotor speed (RPM) vs. variation in input Voltage, c) Variation of torque vs. variation in input current at a fixed Voltage, d) Variation of torque vs. variation in rotor speed (RPM) at a fixed Voltage and varying current. A regulated DC power supply unit with a voltage range of 0-30 Volt and a current range of 0-10 Ampere was used to test the prototype with different ranges of Voltage, current and torque. The rotor speed (in RPM) was tested by using a Laser Speed Detector. Torque was calculated mathematically.

Figure 2: Cored PMDC motor used for comparative analysis of performance

To compare the performance of the prototype coreless PMDC motor, a cored PMDC motor, as shown in Figure 2, with same power rating was used. The same test set-up as used for the prototype coreless PMDC motor was used to record the performance characteristics of cored PMDC motor also.

4. Results and Discussion

4.1. Performance Characteristics

The performance characteristics of the developed prototype coreless PMDC motor were compared with a cored PMDC motor of same power rating and the comparison data is represented in suitable graphs.

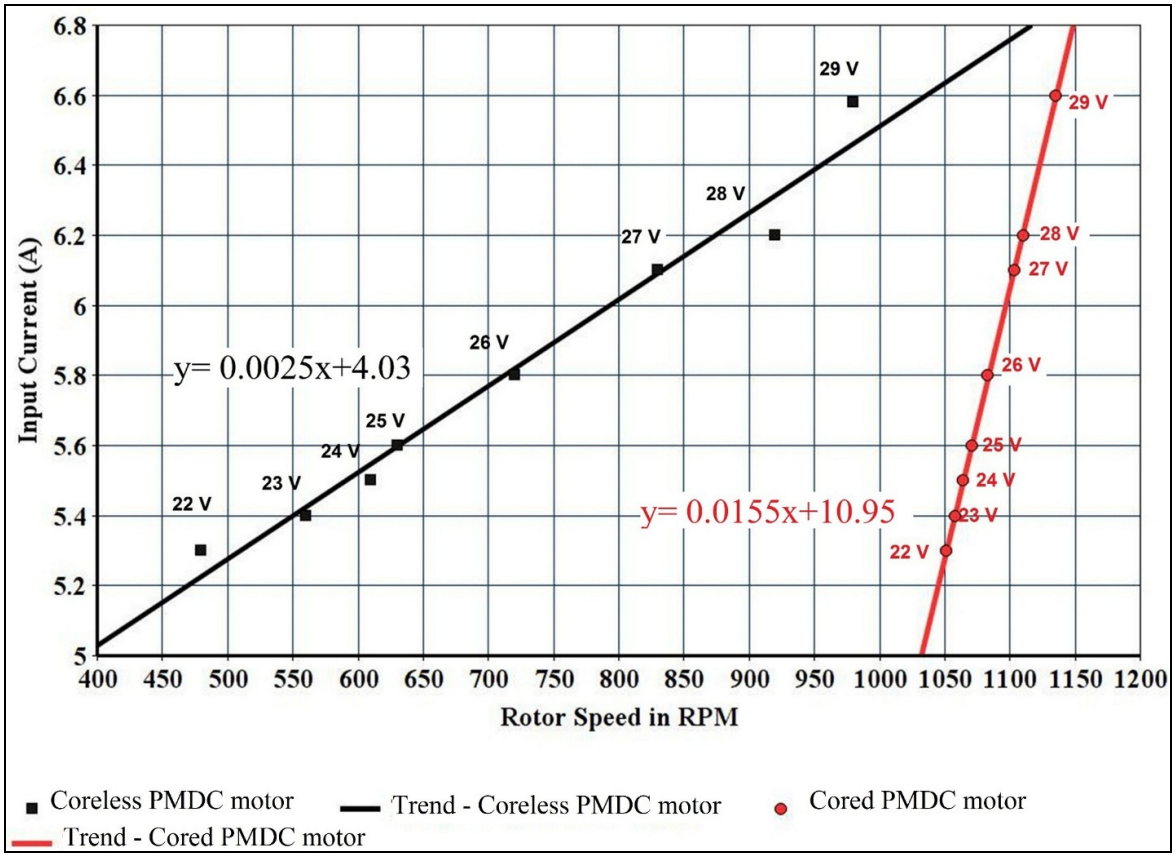

Figure 3: Input Current vs Rotor Speed in RPM.

Figure 3 shows the performance characteristics of input current vs rotor speed in RPM for both the coreless and cored PMDC motors at different Voltages. It is evident from Figure 3 that the coreless PMDC motor has a wider speed range (480-980RPM) compared to cored PMDC motor (1050-1135RPM) for the equal input current range (5.3-6.6A). This feature of coreless PMDC motor helps it to be a better option for applications of varying load where the input voltage and rotor RPM keep changing.

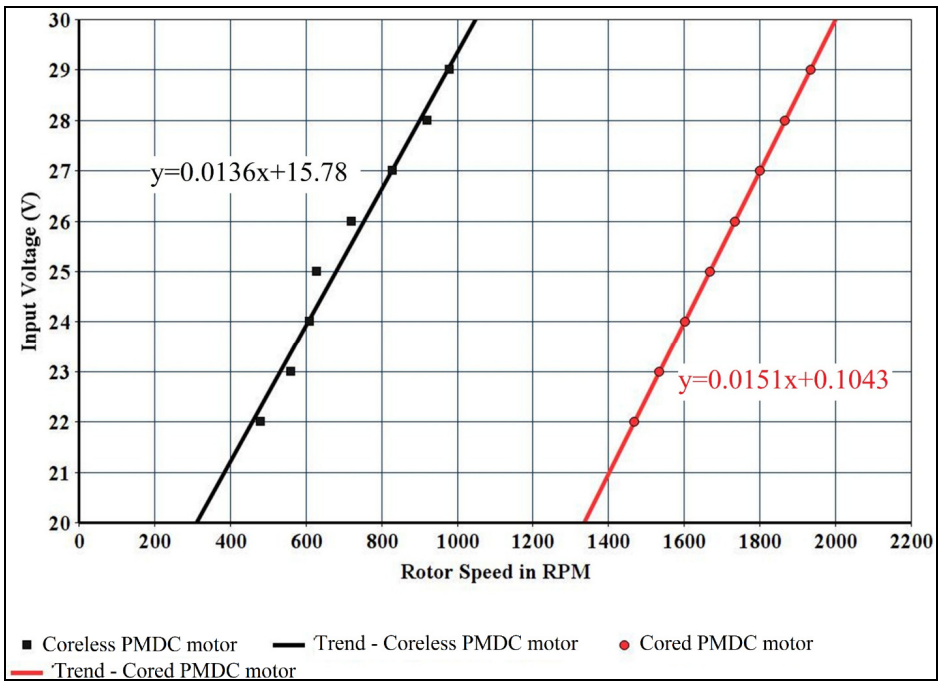

Figure 4: Input Voltage vs Rotor Speed in RPM.

Figure 4 shows the performance characteristics of input Voltage vs rotor speed in RPM for both the coreless and cored PMDC motors. It is seen from this figure that both the motors show almost similar slope of variation in rotor speed with respect to variation in input Voltage. From figure 4 it can also be seen that the rotor speed range (480-980RPM) in coreless PMDC motor is lesser than that of the cored PMDC motor (1050-1135RPM) for the same Voltage range. This shows that for the same input Voltage range, coreless PMDC motor produces more torque in comparison to that of cored PMDC motor since both the motors are of same power rating. This performance feature of the coreless PMDC motor makes it suitable for applications of higher torque range with lower rotor RPM.

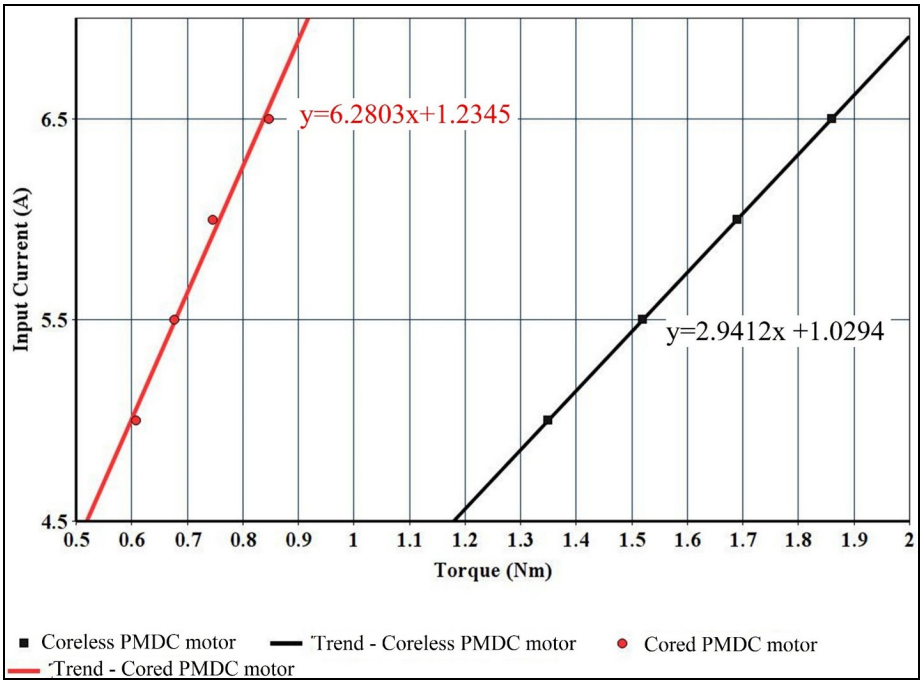

Figure 5: Input Current vs Torque

Figure 5 shows the performance characteristics of Input Current vs Torque. From Figure 5, it is seen that the slope of input current vs torque graph for coreless PMDC motor (2.9412) was significantly lesser as compared to that of cored PMDC motor (6.280). It is evident from Figure 5 that the coreless PMDC motor has a higher and wider torque range (1.35-1.86Nm) as compared to cored PMDC motor (0.61-0.85Nm) for the same input current range.

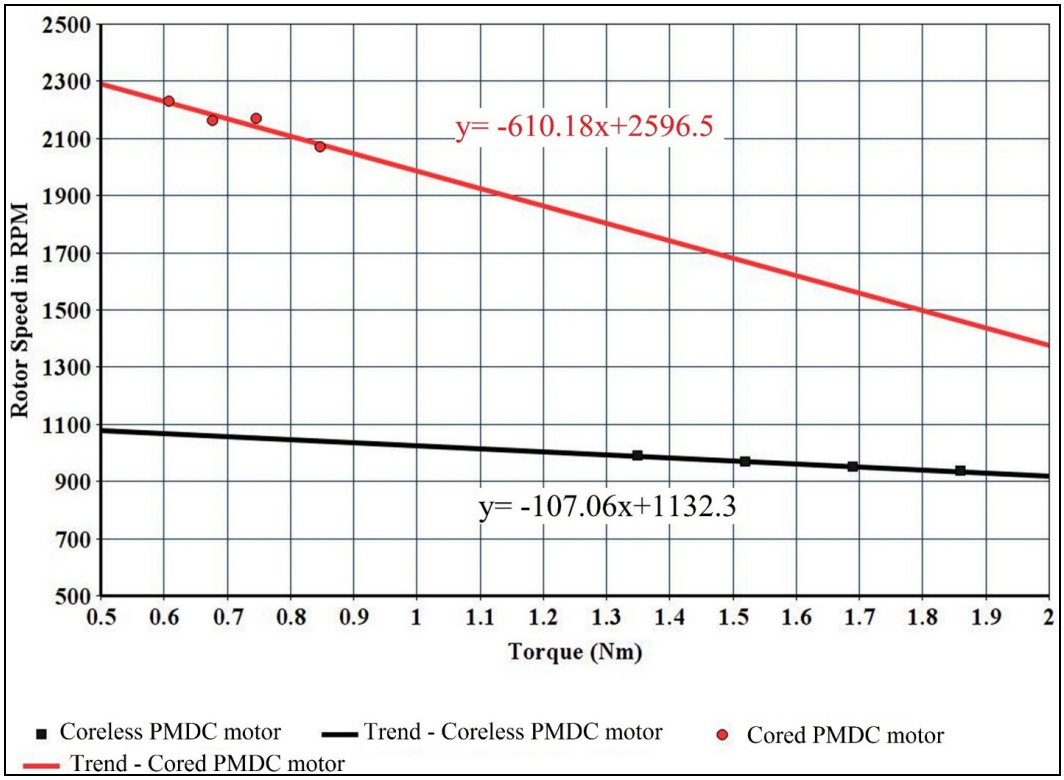

Figure 6: Torque vs Rotor Speed in RPM

Figure 6 shows the performance characteristics with respect to the Torque vs Rotor Speed in RPM. From Figure 6, it is seen that the slope of torque vs rotor speed graph for coreless PMDC motor (-107.06) was much lesser as compared to that of cored PMDC motor (-610.18). Also the torque level was much higher for coreless PMDC motor in comparison with cored PMDC motor. This performance feature of coreless PMDC motor helps it to be considered for applications where there is a requirement of higher torque with a limited variation in rotor speed.

4.2. Cost Analysis

The cost analysis has been represented in Table 2. The items used for developing the prototype were hand wound copper winding, center shaft and support structure, permanent magnets, friction-less ball bearings, wooden frame work and carbon brushes. Cost of labor is not included.

Item	**Mass, kg**	**Cost $**
Winding	0.50	5.00
Shaft and support structure plastic material	0.11	4.50
Permanent Magnets	1.70	6.50
Bearings	0.28	6.00
Frame work and carbon brushes	0.67	5.30
Total	**3.26**	**27.30**

Table 2: Cost Analysis of the Prototype

5. Conclusion

In the present study, a prototype of coreless PMDC motor was successfully developed, tested for its performance characteristics and analyzed for its performance comparison with a cored PMDC motor of the same power rating. It was found that the coreless PMDC motor has a wider speed range compared to cored PMDC motor for the equal input current range and this feature helps the coreless PMDC motor to be a better option for applications of varying load where the input voltage and rotor RPM keep changing.

The results showed that, for the same input Voltage range, coreless PMDC motor produces more torque in comparison to that of cored PMDC motor of same power rating. This performance feature of the coreless PMDC motor makes it suitable for applications of higher torque range with lower rotor RPM. The slope of input current vs torque graph for coreless PMDC motor was significantly lesser as compared to that of cored PMDC motor. It was evident from the results that the coreless PMDC motor has a higher and wider torque range as compared to cored PMDC motor for the same input current range. It was also seen from the results that the slope of torque vs rotor speed graph for coreless PMDC motor was much lesser as compared to that of cored PMDC motor. Also the torque level is much higher for coreless PMDC motor in comparison with cored PMDC motor. This performance feature of coreless PMDC motor helps it to be considered for applications where there is a requirement of higher torque with a limited variation in rotor speed. The cost analysis of the prototype showed that the manufacturing cost is significantly competitive since the laminated steel core is absent in the coreless PMDC motor.

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