Evaluation of E-vehicle Efficiency Enhancement with Magnetic Materials

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Abstract. Electric vehicles (EVs) commonly use BLDC (Brushless DC) motors because of their efficiency, reliability, and low maintenance needs. BLDC motors are perfect for vehicle propulsion because they convert a large portion of electrical energy into mechanical energy, consuming less energy while producing a significant amount of torque. They can be lighter and more compact because of their better power density. Given how important weight and space are in EVs, this is a huge benefit. In applications where smooth operation is crucial, such as electric vehicles (EVs), Detent torque is an undesirable characteristic in BLDC motors. It describes the jerky or uneven spinning brought on by the torque ripple that results from the magnetic interaction among the stator and rotor magnets. The effect of different magnetic materials on detent torque in Brushless DC motors used in Electric Vehicles are analysed in this research.

1 Overview

The transition to EV's is now pivotal in the global pursuit of sustainable transportation. Among various electric motor options, the Brushless DC (BLDC) motor stands emerged as a well-liked option for EVs due to its low maintenance requirements, reliability and efficiency. Unlike traditional motors that rely on brushes for commutation, BLDC motors use electronic control systems to manage power distribution. This not only reduces wear but also enhances performance, making BLDC motors ideal for modern electric vehicles where smooth operation, long life, and energy efficiency are essential. With the rapid advancements in battery technology and motor control systems, BLDC motors in EVs enable smoother rides, reduced energy consumption, and higher torque at lower speeds. This introduction delves into how BLDC motors work, their advantages over other motor types, and their critical role in the future of electric transportation. Internal Permanent magnet Brushless DC motor is the One of the most well-known BLDC motor types in this category.

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In PM-BLDC motors, Detent torque produced by magnetic interaction between the permanent magnets present on the stator's slotted structure and rotor. The magnetic field produced by the permanent magnets in the rotor's turns interacts with the iron teeth in the stator, causing the rotor to align with certain positions of the stator where magnetic reluctance (resistance to magnetic flux) is lowest. This alignment generates a fluctuating torque as the rotor moves from one position to another, known as Detent torque. This article explains the influence of different magnetic materials upon detent torque. At greater temperatures, the magnetic field becomes weaker as the magnet's molecules accelerate. The magnetomotive force is either strengthened or weakened by temperature.

2 Magnetic Materials for PMBLDC

The magnetic materials used in PMBLDC (Permanent Magnet Brushless DC) motors significantly impact the motor's performance, efficiency, size, cost, and overall reliability. In electric vehicles (EVs), where power density and efficiency are critical, the choice of magnetic materials can be a deciding factor in the motor's design and functionality. The commonly used magnetic components are

- NdFeB (Neodymium-Iron-Boron)
- Ferrite Magnets (Ceramic)
- Alnico (Aluminum-Nickel-Cobalt)
- SmCo (Samarium-Cobalt)

2.1 Neodymium-Iron-Boron (NdFeB)

Neodymium-Iron-Boron (NdFeB) magnets are widely used in Permanent Magnet Brushless DC (PMBLDC)motors, especially for electric vehicles (EVs), due to their high energy density and excellent magnetic properties. NdFeB magnets have one of the highest magnetic energy densities among all permanent magnets, meaning they can produce strong magnetic fields with smaller volumes. This is crucial for EVs, as space and weight savings are essential for optimizing efficiency and range. Their high energy density also enables smaller, lighter motors that can produce the same or higher torque than larger motors with weaker magnets, improving the power-to-weight ratio of EVs.

High coercivity (resistance to demagnetization) is important in automotive applications, where the motor often undergoes rapid temperature changes. NdFeB magnets are typically alloyed with dysprosium or terbium to enhance high-temperature stability, though this increases the cost. This allows the motor to maintain performance and durability even at elevated temperatures.

The magnetic strength of NdFeB enables more efficient motor designs, which is critical for EVs as they require a lot of power to operate but must minimize energy consumption to maximize range. Using NdFeB magnets allows PMBLDC motors to operate at high efficiencies with less electrical input, reducing energy losses and battery drain.

In a PMBLDC motor, the rotor (with the NdFeB magnet) and stator generate a magnetic field that produces rotation. NdFeB magnets offer high torque density, which means that the motor can generate more torque in a smaller space. High torque density leads to improved acceleration and better responsiveness, important for EV performance. In order to lower detent torque and boost the PMBLDC motor's efficiency, we are using a new grade of NdFeB magnetic materials in this investigation.

3 Design Process

The design process, which is based on the technique from [1, 2]. With characteristics including a peak torque of 400 Nm, a peak speed of 6000 rpm, and 50 kW of maximum power output at 25% of the maximum speed, the motor is designed to be used in hybrid electric vehicle traction. We are designing the PMBLDC motor with 48 stator slots, eight rotor poles, a 0.5 mm air gap, 75 mm of stack length, and 242mm is an outer diameter. Design of the engine assumes a lap winding of 6 per pole and 2 coils. The rotor has a 140° magnetic pole arc, 30 mm of slot depth of, 6.5 mm tooth width and a 54 mm per pole of magnetic breadth. Here, we are analyzing the effect on the detent torque in E-vehicles utilizing a different grade of NdFeB magnetic materials by using multiposition simulation in Altair Flux software.

- Start a new flux 2D project.
- Open the Brushless Permanent magnet motor model from Overlay.
- Assign the design specification values for Geometrical Representation (General, Airgap, Stator, Rotor & Winding)
- Meshing all the motor model.
- Fix the Physical description using Transient magnetic 2D from Define option.
- Choose the material for Stator & Rotor from Material Manager.
- Assign the values in the face region for stator & rotor.
- Orienting magnetic materials & save the designed project.
- Check physics for Required BLPM Dc motor.
- To find Detent torque go Solving Scenario
- For Graphical representation select Isovalue from Graphic.
- Stop & save the Process.

4 Detent Torque Analysis

The Altair flux software is used for simulation to find the detent torque. The velocity is set at one mechanical degree per second or 1/6 rpm. The angle of the rotor can be changed over 7.5, or one slot pitch. The analysis uses the range 0 to 7.5 with the step value of 0.1875.

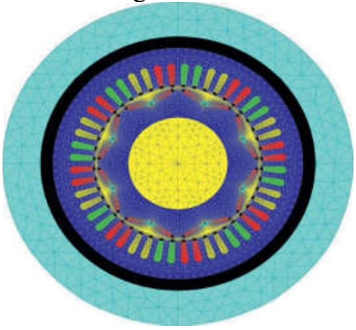

Figure 1: Mesh domain

- The silicon steel lamination COGENT_M270_35A_50HZ has been chosen as the core. Two magnetic materials (NdFeB and compression molded magnets MQP_14_12_180D) are examined for their effects. The first step in the mesh generation process was to set the geometric parameters, as shown in Image 1.
- NdFeB is made from an alloy of neodymium, iron, and boron. These most powerful permanent magnets available and are employed in many different applications, such as medical equipment, sensors, and high-performance motors.
- CY_N35_20DEG refers to a neodymium (NdFeB) magnet of grade N35, Linear magnet which offers moderate magnetic strength. The 20DEG likely indicates that it is rated for use at up to 20°C without significant loss of magnetic performance, making it suitable for low-temperature applications. CY_N35_20DEG - Residual magnetization is 1.210 T .
- MQP_14_12_180D refers to neodymium-iron-boron (NdFeB) magnetic powder, with a maximum energy product of 14 MGOe and remanence of 12 kG, indicating moderate magnetic strength. The 180D denotes high coercivity, making it resistant to demagnetization, ideal for demanding magnetic applications. The Remanent flux density (T) of MQP_14_12_180D is 0.462T.

5 Results and Discussion

The numerical findings for the NdFeB compression molded magnet's Angular speed, Detent torque, and angular position are shown in Tables 1 – 2. Type 1 and 2 illustrate the two magnetic material impacts, respectively, using NdFeB and compression molded magnets MQP_14_12_180D. The machine's magnetic flux density distribution is displayed in Images 2-3. Images 4 and 5 display the graphical results accordingly. when rotor permanent magnets made of NdFeB and compression molded magnets are present.

The impact of Detent torque is seen to be lessened by the composite molded magnets. The maximum magnitudes of Detent torque are 7.847 Nm, 0.539 Nm for NdFeB, compression molded magnets, respectively with constant angular speed.

- Type 1: Magnetic material - CY_N35_20DEG.
- Type 2: MQP_14_12_180D.

This study investigates how NdFeB compression-molded magnets affect Detent torque. The greatest Detent torque values for NdFeB are 8.015 Nm, while for compression-molded magnets, they are 0.784 Nm, in accordance with earlier research [3]. However, we are incorporating the molded magnet MQP_14_12_180D into the same process as before while also carrying out the multiposition simulation. Our results show that the maximum Detent torque values for NdFeB are 7.847 Nm, while the Detent torque for compression-molded MQP_14_12_180D is 0.539 Nm. In compression molded magnets (MQP_14_12_180D), the Detent torque can be reduced by up to 98% when compared to NdFeB.

6 Conclusion

The compression-molded magnets produce the largest dip, up to 98% up to 180-degree temperature. Through mesh creation, mechanical parameter adjustments, and physical analysis using a flux simulation tool, these findings were obtained. By starting the rotor at 7.5°, the phase current was matched with the back EMF. Application temperature, weight, device size and cost are the main factors that affect the choice of magnetic material in E-vehicle.

6.1 Images and Tables

Table 1 Motor Specifications for Type 1.

Particulars	**Value**
Detent Torque (Minimum)	-7.847 Nm
Detent Torque (Maximum)	7.847 Nm
Detent Torque (Mean)	-0.002 Nm
Detent Torque (Rectified Mean)	3.804 Nm
Detent Torque (RMS)	4.663 Nm
Angular Speed	1 rad/s
Angular Position Range	0 to 7.5 radians

Table 2 Motor Specifications for Type 2.

Particulars	**Value**
Detent Torque (Minimum)	-0.539
Detent Torque (Maximum)	0.539
Detent Torque (Mean)	0.0002
Detent Torque (Rectified Mean)	0.1899
Detent Torque (RMS)	0.2727
Angular Speed	1 rad/s
Angular Position Range	0 to 7.5 radians

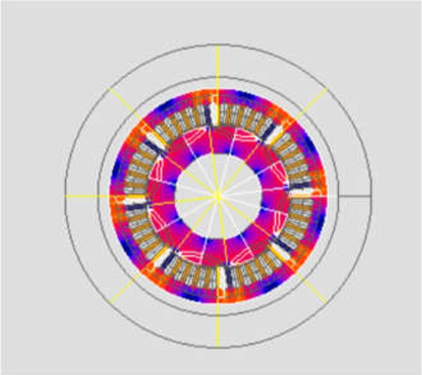

Figure 2 - Magnetic Flux Density Distribution View for Type 1.

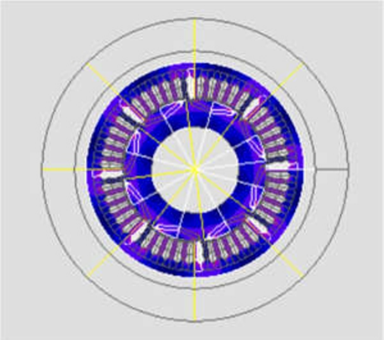

Figure 3 - Magnetic Flux Density Distribution View for Type 2

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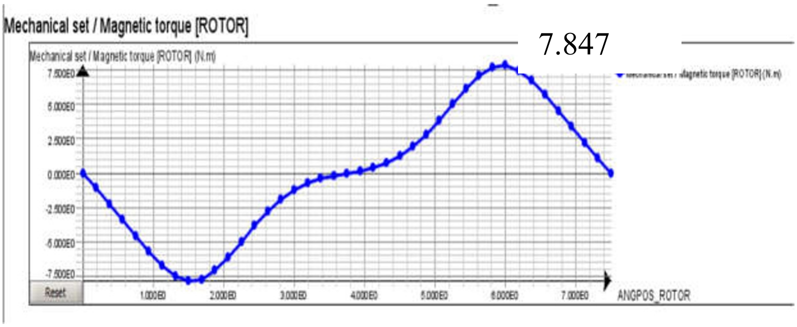
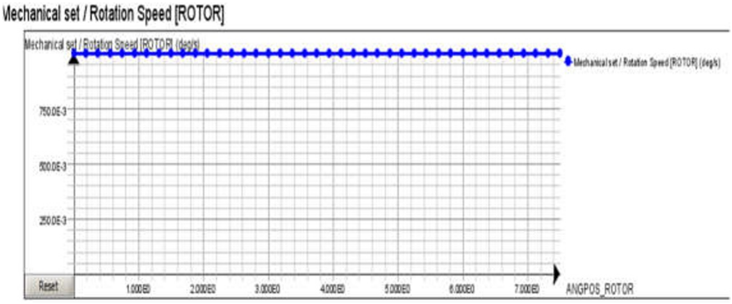
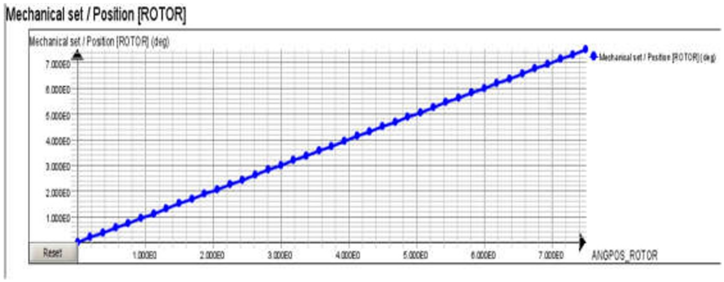


Figure 4 BLDC Motor parameters for Type 1[CY_N35_20DEG] Angular position [ROTOR] VS Magnetic torque [ROTOR]



Angular position [ROTOR] VS Rotation Speed [ROTOR]



Angular position [ROTOR] VS Position [ROTOR]

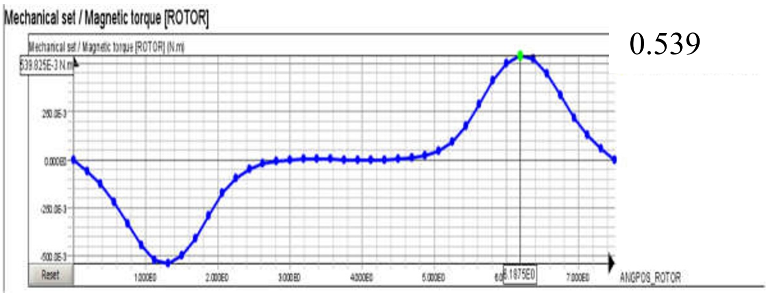
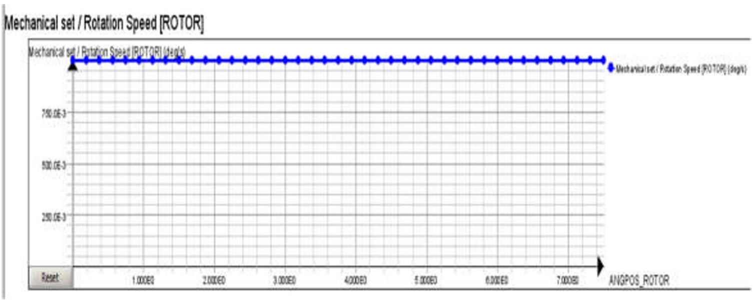
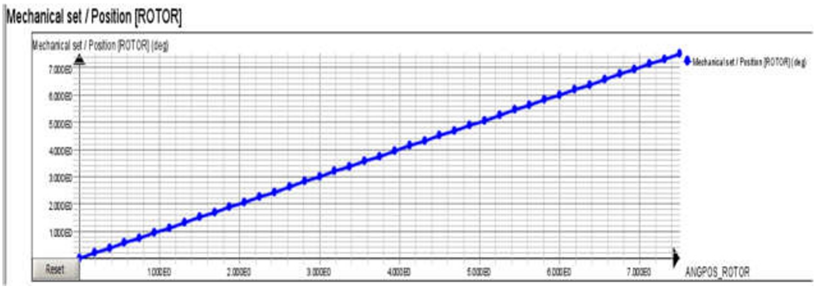


Figure 5 BLDC Motor parameters for Type 2 [MQP_14_12_180D] Angular position [ROTOR] VS Magnetic torque [ROTOR]



Angular position [ROTOR] VS Rotation Speed [ROTOR]



Angular position [ROTOR] VS Position [ROTOR]

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