Evolution and Analysis of Brush Structures in Brushed Motors

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Abstract. Based on the law of electromagnetic induction, DC motors have undergone significant technological advancements since their invention in the 19th century, becoming essential in industrial and household applications. However, traditional brushed DC motors face a major drawback: severe internal wear caused by mechanical friction between the brushes and commutators, which reduces their efficiency and lifespan. This paper analyzes the structure and working principles of brushed DC motors, investigates the causes of brush wear, and proposes solutions such as lubricants, automatic replacement systems, and carbon nanotube-based materials. Additionally, it reviews the development history of DC motors and discusses future prospects for enhancing performance through advanced materials and intelligent technologies like IoT-enabled monitoring systems. Although brushed DC motors have limitations in complex environments, their low cost, simple design, and reliability ensure their irreplaceability in specific applications. This study aims to provide insights into improving motor durability and efficiency while maintaining their practical advantages.

Keywords: Brushed DC motor, wear, electric brush, commutator.

1. Introduction

On the base of the law of electromagnetic induction, the DC motor was invented, from 1831 when electromagnetic induction was first discovered to the wide application of brushed DC motors. These motors are widely used due to their adjustable rotating speeds, high torque capabilities, simple and cost-effective design, flexibility in various conditions, and availability in diverse sizes and shapes [1]. As the technology upgraded, the defects of DC motor are no longer neglectable. Brushed DC motor has a common disadvantage in that the brushes and the commutator inside it wore and tore easily, which means it needs replacement frequently and has a non-negligible possibility of breaking at any moment. One probable solution for reducing energy loss and time consumption is to add lubricating oil or apply an auto-replacing system to reduce the time consumption instead. On the base of knowledge about the motor and its principles, and considering its actual use, a new structure can be set up and offer a chance to exploit the potential of the DC motor. Current information can be summarized and provide easily comprehended theory and thoughts about brushed DC motors to help create clearer ideas about the structures of DC motors. This article aims to analyses the main cause and consequences of wearing in brushed DC motor and suggest some practical solutions to extend the lifespan of brushed DC motors.

2. Principle & structure

A brushed DC motor consists of a bundle of rotating coils connected with commutators, with brushes connected to the DC voltage. There’s a permanent magnet on two sides of the structure. When a DC voltage is applied, a current occurs in the coil, with the permanent magnet around the coils, the law of electromagnetic induction applied and the ampere’s force induced causes the coil to rotate. The ampere’s force initially acts in one direction but will eventually oppose the rotation. The brush and commutator pairs are used to make the ampere’s force direct to the same direction all the time to ensure the motor functions properly [2].

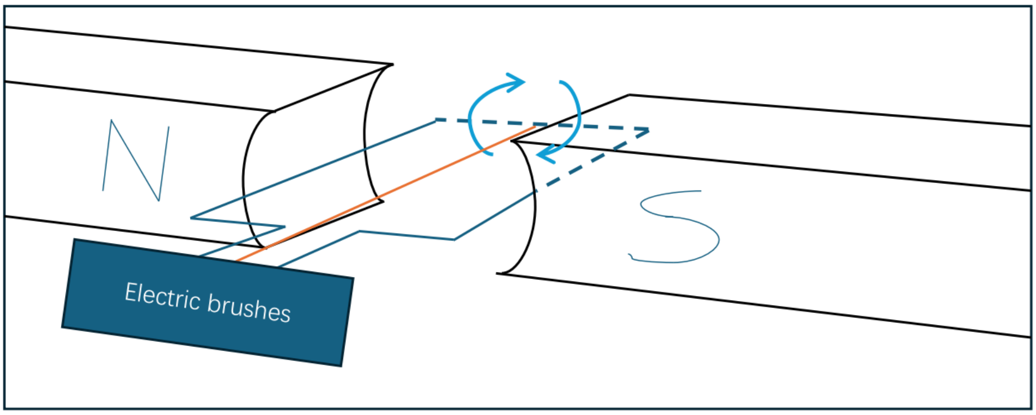

Figure 1. Simple structure of DC motor

2.1. Stator

The stator consists of a pedestal, a permanent magnet, electric brushes, and a bearing. The pedestal supports the entire structure, the permanent magnet produces a magnetic field, electric brushes connect the DC voltage and the bearing fixes the position of the rotor. The stator induces a magnetic field around the rotor waiting for use.

2.2. Rotor

The rotor, also known as the armature, consists of windings crossing through each other. As current flows through the coils, they will cut the magnetic field, and electromagnetic induction law is applied to produce ampere's force perpendicular to both the direction of the current and magnetic field. The force causes a torque and rotates the bearing; mechanical energy is then produced.

2.3. Electric Brushes and commutators

The brushes and commutator are made of conductors including graphite or segmented copper sleeve in general, with some metal powder in the material to increase the conductivity and durability of brushes. The electric brushes work together with the commutators; each pair of commutators can form half of a circuit. With brushes connected to it directly, a circuit is formed, and current occurs in the circuit. As the commutator pairs rotate and brushes lie still, every circuit formed will last for a short period of time and then be disconnected. Every single part of rotation from one commutator to another, the brushes will be connected to the next pair of commutators, and then the current will occur continuously in the coil that is perpendicular to the direction of the magnetic field formed by the permanent magnet. So, the current inside the motor can be seen as passing through a stationary circuit relative to the magnetic field. Then the electromagnetic induction law can induce a vertical force to rotate the rotor continuously and produce a rotating force through the bearing.

3. Analysis about wearing problems

There are always some electric brush contacts in the important part of motors, taking the role of conducting electricity and letting brushes exposed to the mechanical and electrical loading. Wear is often related to temperature, material quality, speed, contact force, and environmental conditions [3].

Current solutions include using more durable brushes, reducing rotation speed, and using smaller currents. Most of those will contain problems of not solving the root of the problem or sacrificing power or efficiency. No matter how strong the electric brushes are, they will eventually wear out over time.

The fundamental principle of the motor includes the use of brushes and a commutator. There exists a problem of wear and tear due to frictional force against the rotation since the brush is a conductor means that it has to connect with the commutator, which is rotating very fast, the problem of wear can be demanded to eliminate unless changing the DC motor into a brushless motor.

3.1. Solutions to brush wear: Lubrication, Auto-Replacement systems, and advanced materials

3.1.1. Lubricating oils: Types and applications

Mineral oil lubricants consist of hydrocarbons and additives that use raw materials fines from crude oil at a cheap expense. Which is fit for use in motors in family applications, small-size motors, and low-load industrial machines. The best working condition of mineral oil is about -20℃~120℃ which fit the general working condition of DC motors. These types of lubricants can fit the condition of circumstances of DC motors very well, as they are compatible with various kinds of additives to adapt to the wide range of uses of DC motors. Its compatibility also limits its extreme condition and can last for a short period of time that it needs to supply frequently.

Synthetic oil lubricants consist of alcohols, poly α-olefins, and silicon oil produced by chemosynthesis with a long producing process. This type of lubricant is suitable for high-speed motors, sophisticated machines, and aerospace equipment. Unlike mineral oil lubricants, synthetic ones have a longer lifespan and are able to be used in extreme temperature conditions as the type of lubricants can work under temperature between -40℃~150℃. The price is that it has a high cost and is incompatible with a majority of additives, even the sealing coating such as fluor elastomers could be corrupted by synthesis oil lubricants which harm the motor dangerously [4]. It also causes engine damage and degrades faster compared to mineral oil when used in motor [5].

In contrast, some research shows that the waste lubricating oil used for motors is a hazardous pollutant to the environment. The chemical composition can spread out quickly and cause extreme environmental problems [6]. The dangers of using lubricating oil have attracted many people's eyes and we can no longer bear the negative impact caused by the usage of lubricating oil.

3.1.2. Auto-Replacement systems for brushes

The root of the problem is that replacing the brush is time-consuming and sometimes expensive. So, if there is a pair of spare electric brushes, the time consumption can be eradicated by automatically swapping to spare brushes and adding new spare electric brushes. With an auto-replacing system, it is no longer a problem to minimize the time consumption. The system is quite simple, including a mass-sensitive structure besides the brushes that once the electric brush rots severely, the brush will lose its support and fall, with a new electric brush replacing the original position of the brush. With a conductor between the replacing brush's position and the wire, the brush can be replaced with a minimized loss of rotating speed. The system could include a brush lifespan prediction system, which supervises the rot level of brushes predicts when it will fail, and changes the brush just before it fails with the help of programming that can determine the wearing intensity of brushes [7] [8]. These methods avoid the complex process of replacing brushes. The system can easily be controlled, with the problem of mass sensation not precise enough.

3.1.3. Carbon-Nanotube-Based brushes: Performance and potential

The type of brush offers high-performance potential through the use of carbon nanotubes, which reduce the coefficient of friction to as low as 0.08, a significant improvement over graphite brushes that typically range from 0.15 to 0.25. These advanced brushes exhibit excellent electrical and thermal conductivity, high mechanical strength, and remarkable stability in varying environmental conditions. Furthermore, they operate with minimal noise and produce low electromagnetic interference, making them highly suitable for applications requiring quiet and efficient performance [9]. Their durability and efficiency make carbon nanotube-based brushes a promising solution for enhancing the lifespan and reliability of brushed DC motors in industrial and commercial settings [10].

3.2. DC motor VS brushless DC motor (BLDC)

Brushed and brushless DC motors each have distinct characteristics that make them suitable for different applications, particularly when considering wear, performance, and cost. The most significant drawbacks of brushed DC motors is the mechanical wear as analyzed before. Over time, this wear leads to a degradation in performance and eventually necessitates maintenance or replacement. Carbon brushes, commonly used in brushed motors, are designed to be replaceable, but the commutator itself also wears out, ultimately limiting the motor's lifespan. In contrast, brushless DC motors (BLDC) eliminate this issue entirely by replacing mechanical commutation with electronic control, resulting in significantly longer operational lifetimes and reduced maintenance requirements.

When comparing the advantages and disadvantages of the two motor types, brushed motors are generally more cost-effective and simpler to control, making them suitable for low-cost applications such as toys or infrequently used devices like power windows in cars. However, they suffer from lower efficiency, higher electrical noise due to brush arcing, and limited speed and acceleration capabilities. On the other hand, brushless motors offer higher efficiency, quieter operation, and superior performance in terms of speed and acceleration. These benefits come at the cost of more complex drive electronics, which increase the overall system cost. Despite this, the declining cost of electronics has made brushless motors increasingly attractive for high-performance applications.

In terms of application scenarios, brushless motors are preferred in environments where reliability, efficiency, and low maintenance are critical, such as in automotive pumps and fans. Their ability to operate quietly and with small torque also makes them ideal for high-end applications like seat adjustment motors in luxury vehicles. In contrast, brushed motors remain relevant in low cost and low duty cycle applications where the total runtime is minimal, and the simplicity of design outweighs the need for high performance or long lifespan.

The choice between brushed and brushless motors depends on the specific requirements of the application, and the balanced point between factors such as cost, performance, and maintenance. With advanced technology, brushless motors are becoming more accessible, gradually replacing brushed motors in many traditional applications [11].

3.3. Problem and improvement throughout the history

In 1821, Michael Faraday discovered electromagnetic induction law, laying the groundwork for the innovation of motors.

In 1832, William Sturgeon made the world’s first practical DC motor with the help of a permanent magnet and rotating armature.

In the 1840s, as far as the DC motor was introduced, the innovation of electric brushes and commutators resolved the problem of changing direction continuously, making the motor able to rotate smoothly.

In the 1860s, Zénobe Gramme improved the design of armature and increased the efficiency, reliability and lifespan of brushed DC motors.

Before the 1890s, the material used to make the motor was made of pure copper, which has enough conductivity but with very low hardness which broke easily. It is a serious problem that reduces the lifespan of motors and causes severe inefficiency. The early motor is unable to support industrial-size machines and malfunctions frequently.

In the 1890s, graphite and carbo material substituted the usage of copper brushes, reducing the wear of electric brushes and raising the lifespan of brushed DC motors significantly.

After the 1900s, the introduction of Rare Earth Permanent Magnets (REPM) and high-temperature superconductive materials further improved the power, efficiency and lifespan of brushed DC motors.

In the 1970s, the introduction of permanent magnetic materials simplified the structure of motors and removed unnecessary parts. Decrease cost and increase efficiency simultaneously. In the same period, a type of Silicon Controlled Rectifier (SRC), often called thyristor, was introduced to make the control of the speed of rotation more precise and highly efficient to reduce extra wearing.

1980~2000, problems like sparkles of the electric brushes and commutator while running are concerned, the problem results in unnecessary loss of energy and high wear and tear frequency which increase the maintenance cost. The connection between electric brushes and commutators generates noise and electromagnetic interference, which makes it impossible to use in sophisticated structures and quiet circumstances.

After the 2000s, the occurrence of brushless motors occupied the living space of brush motors in the advantage of their high efficiency, long lifespan, and low maintenance cost. A majority of the application of brush motors had been replaced by brushless ones. The innovation of more types of brushed DC motors had been limited by the technical boundary caused by the core ----electric brushes and commutators.

3.4. Future prospects

In the future, the application of new materials and intelligence is the probable route of upgrades of brushed DC motors to make motors suitable for medical devices and increase the portability of associated electronic devices. For example, the system Internet of Things can be installed in machines to predict overloading a fault current and remind the user to decrease its probability of failure, the use of soft magnetic materials with better quality and remarkable DC properties under specific conditions [12] [13]. Also, with the help of the Internet of Things, the brushed DC motors can realize remote monitoring and auto-adopting control.

The complex structure of the brushed DC motor will be a critical problem in the process of miniaturization of the size. Although the cost of a brushed DC motor is very low, the overall cost, including maintenance cost and energy loss, is far larger than brushless one which makes its priority lower. The extreme temperature, pressure, or strong corrosive environment will malfunction the motor, and its flexibility to surroundings is extraordinarily poor.

4. Conclusion

This paper provides a deep analysis of the structure, working principles, and wearing issues of brushed DC motors, proposing various solutions to extend their lifespan and enhance performance. The study suggests frictional force between the brushes and commutators as the primary cause of wear. While existing solutions such as lubricants, auto-replacement systems, and carbon nanotube-based materials have partially mitigated wear, they still have limitations. Future research should focus on various directions. For example: Developing advanced composite materials to enhance brush wear resistance by incorporating nanomaterials or high-performance composites, the conductivity, mechanical strength, and wear resistance of brushes can be improved, reducing wear frequency and extending brush lifespan. To utilizing IoT technology for real-Time brush condition monitoring, integrating sensors and IoT technology to monitor brush wear status, temperature changes, and current fluctuations in real time might be a good choice. This enables the prediction of brush failure and facilitates automatic replacement, minimizing downtime and maintenance costs. Moreover, optimizing motor structure design for complex environments such as high temperatures, high pressure, or highly corrosive environments will enhance the adaptability and reliability in extreme conditions. This target can be achieved by developing new motor structural designs with the help of advanced materials. Exploring applications of intelligent control systems can be realize via leveraging AI algorithms to optimize motor operating parameters, reduce unnecessary energy loss and wear, and further improve motor efficiency and lifespan.

As the part of starting point of a new era, the brushed DC motor had shown its power and exited the arena of mechanical devices quickly. The future stage does not seem to obligate a seat for it, but it still has the potential to be more efficient. The wearing problems can hardly be eliminated, but by the previous methodology, it is possible to minimize the overall cost of construction of brushed DC motors. The ideas directly related to the functions and quality of brushed DC motors enable related people to have a deeper understanding of fundamental problems in the motors and thus develop knowledge to solve them easily.

Despite the limitations of brushed DC motors in complex environments, their low cost and simple structure make them irreplaceable in specific applications. Through innovations in materials, intelligent technologies, and structural design, brushed DC motors have the potential to achieve a higher performance in the future. Motors application is wider than expected, from house electronics to vehicles and intelligent models. Based on this, the relevant engineers should consider their actual situation and circumstances when choosing the motor used to maximize efficiency.

The brushed DC motor has a strong potential in the interior of simple electronics and usage in under-developed areas, in the advantage of simple construction and the cheap cost of materials. These points make brushed DC motors able to have greater potential strength in building a bridge between the underdeveloped industry and the developed one.

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