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Brushless DC Motor: Construction and Applications

Rithvik Gambhir, Akshay Kumar Jha,
SELECT, VIT University Vellore-632014, Tamil Nadu, India
Project Guide: Sudha R SELECT, VIT University Vellore-632014, Tamil Nadu, India

ABSTRACT
Conventional dc motors are highly efficient and their characteristics make them suitable for use as servomotors. However, their only drawback is that they need a commutator and brushes which are subject to wear and require maintenance. When the functions of commutator and brushes were implemented by solid-state switches, maintenance-free motors were realised. These motors are now known as brushless dc motors. This paper deals with the construction, working principle and various applications of the Brushless DC Motor (BLDC). The Brushless DC Motor is also compared with the conventional DC motor and AC Induction motor.

KEYWORDS*— Brushless DC Motor, AC Machines, DC Machines, Hall Effect.*

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I. INTRODUCTION

The concepts behind converting electrical energy into mechanical energy have been known since the late 1820's when the first electric motor was successfully tested. British scientist Michael Faraday first experimented with the idea of the electromagnetic induction motor in the early 1800's. By 1828 the DC Motor was introduced with three main components: the stator, rotor, and commutator. During that time, DC Motors operated similar to Brush DC Motors today, in that they had current flowing through the windings of the motor. In 1837 Americans Thomas and Emily Davenport transformed Faraday's DC Motor into one that could be used for commercial use. These DC Motors became popular in printing presses and powered machine tools. However, with the high cost of battery power, the demand was too small to keep them successful. In 1886, Frank Julian Sprague introduced the first practical DC Motor that was capable of constant speed under variable loads.

Conventional dc motors are highly efficient and their characteristics make them suitable for use as servomotors. However, their only drawback is that they need a commutator and brushes which are subject to wear and require maintenance. When the functions of commutator and brushes were implemented by solid-state switches, maintenance-free motors were realised. These motors are now known as brushless dc motors. The Brushless DC Motor was quite expensive when first introduced, the advancements in design and materials drastically lowered costs and made the Brushless DC Motor a popular selection for many different applications. As of today there are over 15 types of various DC and Ac motors that all serve the purpose of converting electrical energy into mechanical energy or vice versa.

II. CONVENTIONAL AND BRUSHLESS DC MOTOR: A COMPARISON

Although it is said that brushless dc motors and conventional dc motors are similar in their static characteristics, they actually have remarkable differences in some aspects. When we compare both motors in terms of present-day technology, a discussion of their differences rather than their similarities can be more helpful in understanding their proper applications. Table 1 compares the advantages and disadvantages of these two types of motors. When we discuss the functions of electrical motors, we should not forget the significance of windings and commutation. Commutation refers to the process which converts the input direct current to alternating current and properly distributes it to each winding in the armature. In a conventional dc motor, commutation is undertaken by brushes and commutator; in contrast, in a brushless dc motor it is done by using semiconductor devices such as transistors.

TABLE I
Comparison of Conventional and Brushless DC Motors

	Conventional motors	Brushless motors
Mechanical structure	Field magnets on the stator	Field magnets on the rotor Similar to AC synchronous motor
Distinctive features	Quick response and excellent controlability	Long-lasting Easy maintenance (usually no maintenance required)
Winding connections	Ring connection The simplest: Δ connection	The highest grade: Δ or Y-connected three-phase connection Normal: Y-connected three-phase winding with grounded neutral point, or four-phase connection The simplest: Two-phase connection
Commutation method	Mechanical contact between brushes and commutator	Electronic switching using transistors
Detecting method of rotor's position	Automatically detected by brushes	Hall element, optical encoder, etc.
Reversing method	By a reverse of terminal voltage	Rearranging logic sequencer

Brushless DC motors are identical in construction to an AC motor. But controller implementation in BLDC motors is different and that is what that makes BLDC a DC motor. In AC motors sinusoidal current is supplied to each of the two legs with appropriate phase difference. But in BLDC motors, electronic controllers are used to feed full positive and negative current to two phases at a time. The major implication of this feature is that BLDC are very suitable for logic controllers and battery power sources that operate on DC. So BLDC are widely used in computers, cars etc.

III. BLDC: CONSTRUCTION

BLDC motors have many similarities to AC induction motors and brushed DC motors in terms of construction and working principles respectively. Like all other motors, BLDC motors also have a rotor and a stator.

A. Stator

Similar to an Induction AC motor, the BLDC motor stator is made out of laminated steel stacked up to carry the windings. Windings in a stator can be arranged in two patterns; i.e. a star pattern (Y) or delta pattern (Δ). The major difference between the two patterns is that the Y pattern gives high torque at low RPM and the Δ pattern gives low torque at low RPM. This is because in the Δ configuration, half of the voltage is applied across the winding that is not driven, thus increasing losses and, in turn, efficiency and torque.

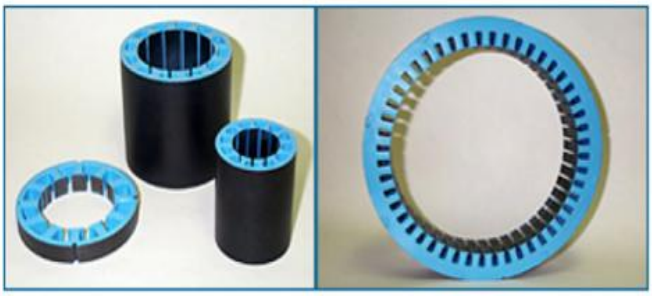

Fig. 1 Laminated Steel Stapings in Stator

Steel laminations in the stator can be slotted or slotless as shown in Figure 2. A slotless core has lower inductance, thus it can run at very high speeds. Because of the absence of teeth in the lamination stack, requirements for the cogging torque also go down, thus making them an ideal fit for low speeds too (when permanent magnets on rotor and tooth on the stator align with each other then, because of the interaction between the two, an undesirable cogging torque develops and causes ripples in speed). The main disadvantage of a slotless core is higher cost because it requires more winding to compensate for the larger air gap.

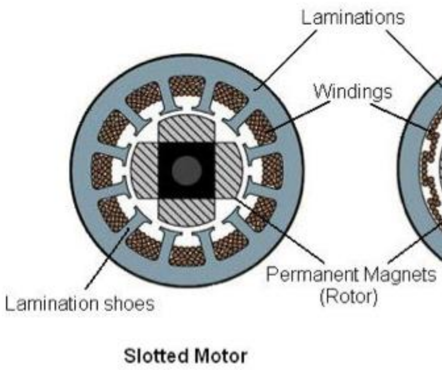

Fig. 2 Slotted and Slotless Motor

Proper selection of the laminated steel and windings for the construction of stator are crucial to motor performance. An improper selection may lead to multiple problems during production, resulting in market delays and increased design costs.

B. Rotor

The rotor of a typical BLDC motor is made out of permanent magnets. Depending upon the application requirements, the number of poles in the rotor may vary. Increasing the number of poles does give better torque but at the cost of reducing the maximum possible speed.

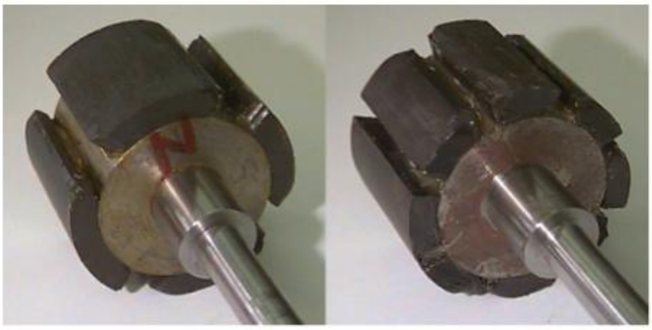

Fig. 3 4 Pole and 8 Pole – Permanent Magnet Rotor

Another rotor parameter that impacts the maximum torque is the material used for the construction of permanent magnet; the higher the flux density of the material, the higher the torque.

IV. WORKING PRINCIPLE: HALL EFFECT

Unlike a brushed DC motor, the commutation of a BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a sequence. It is important to know the rotor position in order to understand which winding will be energized following the energizing sequence. Rotor position is sensed using Hall effect sensors embedded into the stator. Most BLDC motors have three Hall sensors embedded into the stator on the non-driving end of the motor. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined.

Hall Effect Theory: If an electric current carrying conductor is kept in a magnetic field, the magnetic field exerts a transverse force on the moving charge carriers which tends to push them to one side of the conductor. This is most evident in a thin flat conductor. A buildup of charge at the sides of the conductors will balance this magnetic influence, producing a measurable voltage between the two sides of the conductor. The presence of this measurable transverse voltage is called the Hall effect after E. H. Hall who discovered it in 1879.

V. TORQUE/SPEED CHARACTERISTICS

The figure below shows an example of torque/speed characteristics. There are two torque parameters used to define a BLDC motor, peak torque (TP) and rated torque (TR). During continuous operations, the motor can be loaded up to the rated torque. As discussed earlier, in a BLDC motor, the torque remains constant for a speed range up to the rated speed. The motor can be run up to the maximum speed, which can be up to 150% of the rated speed, but the torque starts dropping. Applications that have frequent starts and stops and frequent reversals of rotation with load on the motor, demand more torque than the rated torque. This requirement comes for a brief period, especially when the motor starts from a standstill and during acceleration. During this period, extra torque is required to overcome the inertia of the load and the rotor itself. The motor can deliver a higher torque, maximum up to peak torque, as long as it follows the speed torque curve.

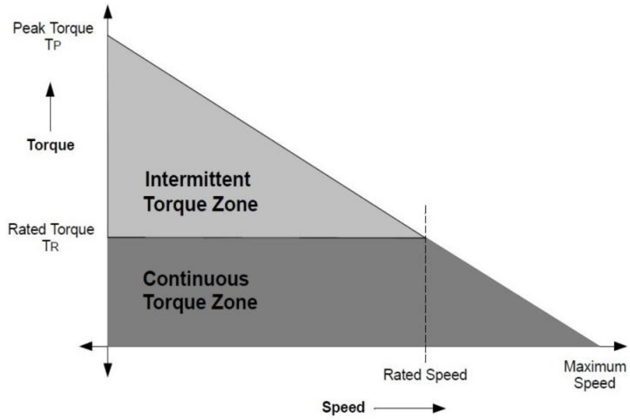

Fig. 4 Torque Versus Speed Characteristics

VI. SELECTING A BLDC

Selecting the appropriate BLDC requires knowing the requirements of the application, such as torque, speed, size, power, length, etc. While determining which Brushless DC Motor best fits the requirements, the controller must be considered as well, as this goes hand in hand with the operation of the Brushless DC Motor. Lastly, environment is important to consider. Applications requiring a harsh, damp environment may require motors with specific IP ratings.

VII. BLDC APPLICATIONS

The cost of the Brushless DC Motor has declined since its introduction, due to advancements in materials and design. This decrease in price, coupled with the many advantages it has over the Brush DC Motor, makes the Brushless DC Motor a popular component in many different applications. Applications that utilize the Brushless DC Motor include, but are not limited to:

- Instrumentation
- Medical
- Appliances
- Automotive
- Factory Automation Equipment
- Aerospace
- Military

A. Laser Printer

In a laser printer, a polygon mirror is coupled directly to the motor shaft and its speed is controlled very accurately in the range from 5000 to 40,000 rpm. When an intensity modulated laser beam strikes the revolving polygon mirror, the reflected beam travels in different direction according to the position of the rotor at that moment. Therefore, this reflected beam can be used for scanning.

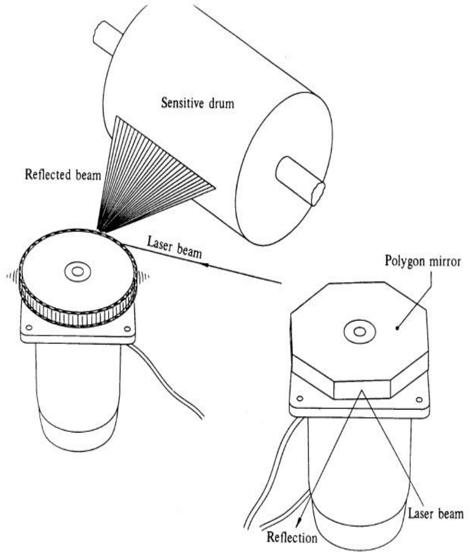

Fig. 5 Role of Motors for Laser Printers; (right) a BLDC driving a polygon mirror, and (above) how to scan laser beams

An image is produced is as follows:
(1) The drum has a photoconductive layer (e.g. Cds) on its surface, with photosensitivity of the layer being tuned to the wavelength of the laser. The latent image of the information to be printed formed on the drum surface by the laser and then developed by the attracted toner.
(2) The developed image is then transferred to normal paper and fixed using heat and pressure.
(3) The latent image is eliminated.

B. Hard Disk

As the main secondary memory device of the computer, hard disks provide a far greater information storage capacity and shorter access time than either a magnetic tape or floppy disk. Formerly, AC synchronous motors were used as the spindle motor in floppy or hard disk drives. However, brushless dc motors which are smaller and more efficient have been developed for this application and have contributed to miniaturization and increase in memory capacity in computer systems. The brushless dc motor is far superior to the ac synchronous motor. Although the brushless dc motor is a little complicated structurally because of the Hall elements or ICs mounted on the stator, and its circuit costs, the merits of the brushless dc motor far outweigh the drawbacks.

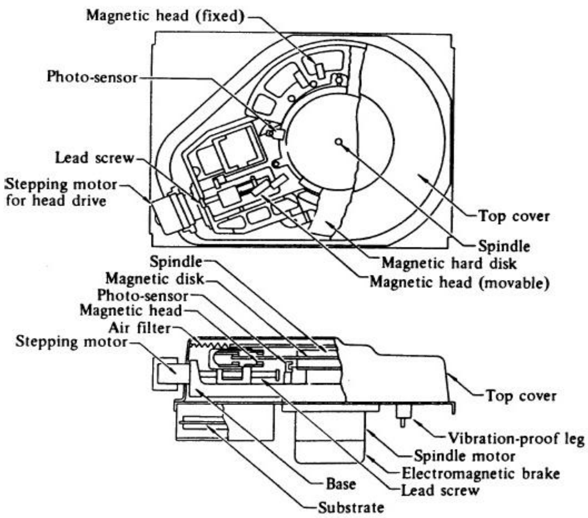

Fig. 6 An Example of Hard Disk Drive (Single Disk Type)

The hard disk drive works as follows: The surface of the aluminium disk is coated with a film of magnetic material. Data is read/written by a magnetic head floating at a distance of about 0.5 μm from the disk surface due to the airflow caused by the rotating disk, and this maintains a constant gap. Therefore, when the disk is stopped or slowed down, the head may touch the disk and cause damage to the magnetic film. To prevent this, this spindle motor must satisfy strict conditions when starting the stopping.

VIII. ADVANTAGES OF BLDC

The absence of brushes in a Brushless DC Motor is perhaps its greatest advantage. The carbon brushes within a Brush DC Motor wear out rapidly and need replacing, which can be costly in the long run. The Brushless DC Motor generates less noise, and is less prone to sparking due to the lack of a commutator. The Brushless DC Motor is typically smaller and lighter than the Brush DC Motor, making it ideal for applications where weight and space are important factors. The Brushless DC motor is cleaner, more powerful, and requires lower maintenance than does the Brush DC Motor. It has higher speed ranges, higher dynamic responses, and ultimately outlasts the Brush DC Motor in total operating hours.

IX. DISADVANTAGES OF BLDC

There are numerous applications using a Brush DC Motor that could instead utilize the Brushless DC Motor. However a few factors might prevent the changeover. The first factor is start-up cost. Although the Brushless DC Motor is lower-maintenance than the Brush DC Motor, initial cost is more expensive, due to its advantageous construction. Second is complexity. A controller is required in order to operate a Brushless DC Motor, and is usually more convoluted than most controllers. A Brushless DC Motor also requires additional system wiring, in order to power the electronic commutation circuitry.

X. BLDC: TYPICAL LIFETIME

The Brushless DC Motor is often considered superior over the Brush DC Motor for its substantially longer lifespan. If run within the given specifications, the Brushless DC Motor can last over 20,000 operating hours based on bearing life. Running a Brushless DC Motor outside of its specifications shortens this lifespan.

Due to the lack of brushes or a commutator, there is nothing to replace within a Brushless DC Motor, making it extremely low maintenance. The only requirement is that the motor be run within proper specifications, and in a clean environment to ensure it does not overheat or result in system failure.

XI. ENVIRONMENTAL CONSIDERATIONS

Precaution must be taken by the user with respect to the environment of the Brushless DC Motor system during operation, repair, and service. The environment, in which a Brushless DC Motor is used, must be conducive to good general practices of electrical equipment. Do not run a Brushless DC Motor system near flammable gases, dust, oil, vapor or moisture. The Brushless DC Motor must be protected by a cover if operated outdoors, ensuring the motor receives adequate air flow and cooling. Any presence of moisture may result in system failure and/or electric shock. Therefore adequate care should be taken to avoid any interaction between the Brushless DC Motor and any kind of moisture or vapors. A Brushless DC Motor should be installed in an environment free from vibration, shock, condensation, dust and electrical noise.

XII. SUMMARY

In conclusion, BLDC motors have advantages over brushed DC motors and induction motors. They have better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation, higher speed ranges, rugged construction and so on. Also, torque delivered to the motor size is higher, making it useful in applications where space and weight are critical factors. With these advantages, BLDC motors find wide spread applications in automotive, appliance, aerospace, consumer, medical, instrumentation and automation industries.

REFERENCES

[1] Justin Damele, “Brushless DC Motor Design and Build,” June, 2011.

[2] Padmaraja Yedamale, “Brushless DC (BLDC) Motor Fundamentals,” 2003 Microchip Technology Inc.

[3] Liu Jinglin, Fu Zhaoyang, Zhao Xiaopeng, “Research on Redundancy high-voltage BLDC motor,” Northwestern Polytechnical University, Xi’an 710072, China.

[4] T. Kenjo, "Permanent magnet and brushless dc motors," Oxford, 1985.

[5] T.J.E. Miller, "Brushless permanent magnet and reluctance motor drive," Oxford, 1989.