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Design of Bearing Commutation in DC Machines

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Abstract— **the focus of the paper is to eliminate the commutator and brushes in a DC machine and integrate the functionality of commutation by changing the design of the ball bearing. The outer ring of the bearing is connected to the external supply, the inner ring is connected to the armature winding and balls conduct between the rings. Further, the paper discusses on the angle of dynamic commutation, voltage drop at the bearing and the performance characteristics of the modified commutator section.**

I. INTRODUCTION

Industrial applications use direct current motors (DC) because the speed-torque relationship can be varied to almost any useful form -- for both motor and regeneration applications in either direction of rotation. Continuous operation of dc motors is commonly available over a speed range of 8:1. Infinite range and smooth control down to zero speed, for short durations or reduced load is also common. DC motors are often applied where they momentarily deliver three or more times their rated torque. In emergency situations, DC motors can supply over five times rated torque without stalling.

II. DC MACHINE WITH BRUSH COMMUTATOR DESIGN

The voltage generated in the armature, placed in a rotating magnetic field, of a DC generator is alternating in nature. The commutation in DC machine or more specifically commutation in DC generator is the process in which generated alternating current in the armature winding of a dc machine is converted into direct current after going through the commutator and the stationary brushes. Again in DC Motor, the input DC is to be converted in alternating form in armature and that is also done through commutation in DC motor.

This transformation of current from the rotating armature of a DC machine to the stationary brushes needs to maintain continuously moving contact between the commutator segments and the brushes. When the armature starts to rotate, then the coils situated under one pole rotates between a positive brush and its consecutive negative brush and the current flows through this coil is in a direction inward to the commutator segments. Then the coil is short circuited with the help of a brush for a very short fraction of time (1⁄500 sec). It is called commutation period. After this short-circuit time the armature coils rotates under South Pole and rotates between a negative brush and its succeeding positive brush. Then the direction of become is reversed which is in the away from the commutator segments. This phenomena of the reversal of current is termed as commutation process. The commutation is called ideal if the commutation process or the reversal of current is completed by the end of the short circuit time or the commutation period. If the reversal of current is completed during the short circuit time then there is sparking occurs at the brush contacts and the commutator surface is damaged due to overheating and the machine is called poorly commutated.

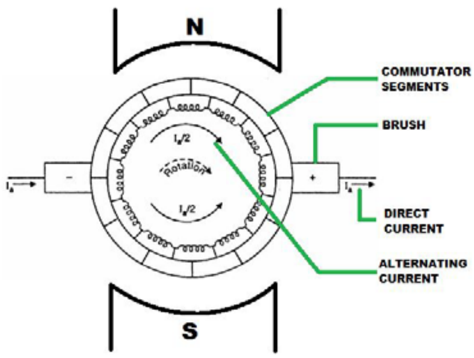


Fig. 1.Physical Concept of Commutation in DC Machine

For the explanation of commutation process, let us consider a DC machine having an armature wound with ring winding. Let us also consider that the width of the commutator bar is equal to the width of the brush and current flowing through the conductor is I_C.

Let the commutator is moving from left to right. Then the brush will move from right to left. At the first position, the brush is connected the commutator bar ‘b’ as shown in Fig. 2. Then the total current conducted by the commutator bar b into the brush is $2I_C$. When the armature starts to move right, then the brush comes to contact of bar ‘a’. Then the armature current flows through two paths and through the bars ‘a’ and ‘b’ as shown in Fig. 2. The total current ($2I_C$) collected by the brush remain same. As the contact area of the bar ‘a’ with the brush increases and the contact area of the bar ‘b’ decreases, the current flow through the bars increases and decreases simultaneously. When the contact area become same for both the commutator bar then same current flows through both the bars as shown in Fig. 2.

When the brush contact area with the bar b decreases further, then the current flowing through the coil B changes its direction and starts to flow counter-clockwise. When the brush totally comes under the bar ‘a’ and disconnected with the bar ‘b’ then current I_C flows through the coil B in the counter-clockwise direction and the short circuit is removed. In this process the reversal of current or the process of commutation is done.

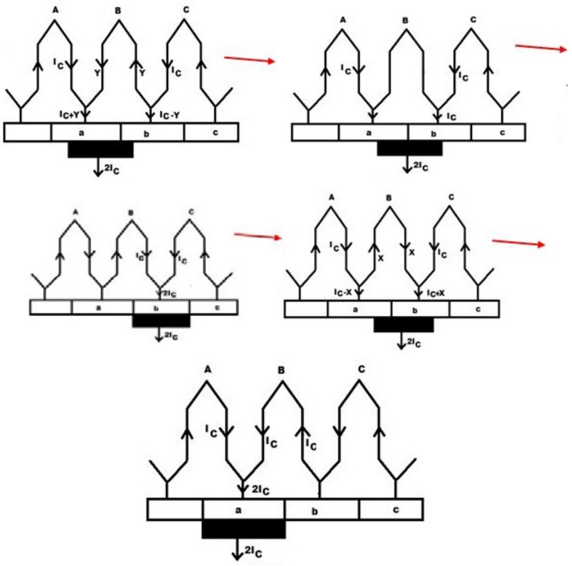


Fig. 2. Commutation in DC Machine

III. COMPONENT MODIFIED

BEARING

A bearing is a machine element that constrains relative motion to only the desired motion, and reduces friction between moving parts. The design of the bearing may, for example, provide for free linear movement of the moving part or for free rotation around a fixed axis; or, it may prevent a motion by controlling the vectors of normal forces that bear on the moving parts. Many bearings also facilitate the desired motion as much as possible, such as by minimizing friction. Bearings are classified broadly according to the type of operation, the motions allowed, or to the directions of the loads (forces) applied to the parts.

Fig. 3. Deep Groove ball bearing

A ball bearing is a type of rolling-element bearing that uses balls to maintain the separation between the bearing races as shown in Fig. 3.

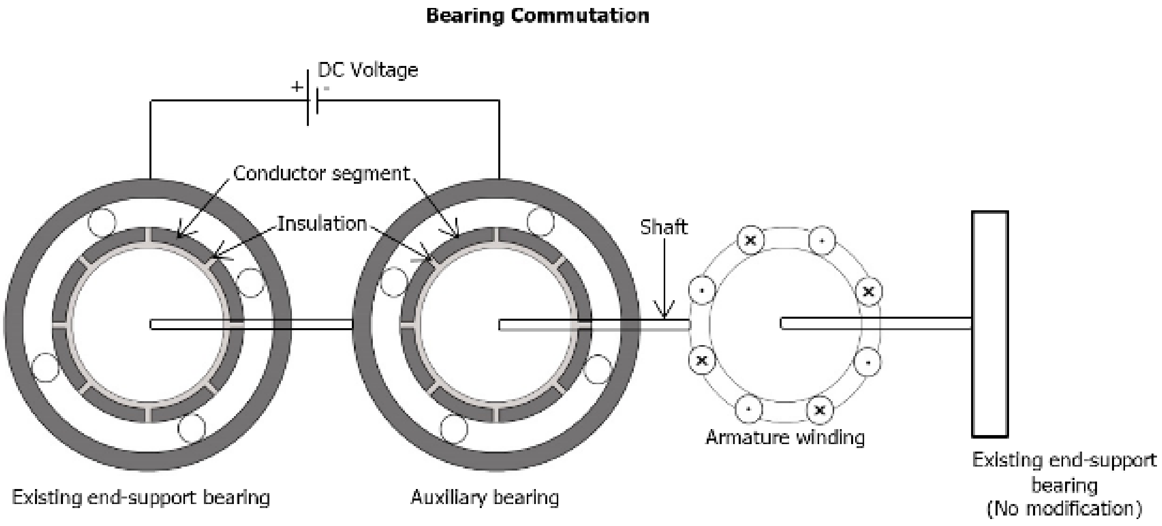
The purpose of a ball bearing is to reduce rotational friction and support radial and axial loads. It achieves this by using at least two races to contain the balls and transmit the loads through the balls. In most applications, one race is stationary and the other is attached to the rotating assembly (e.g., a hub or shaft). As one of the bearing races rotates it causes the balls to rotate as well. Because the balls are rolling they have a much lower coefficient of friction than if two flat surfaces were sliding against each other.

Ball bearings tend to have lower load capacity for their size than other kinds of rolling-element bearings due to the smaller contact area between the balls and races. However, they can tolerate some misalignment of the inner and outer races.

IV. PROPOSED DESIGN

The conventional DC machines employ carbon bristles and metal commutators to transfer power from the stationary part to the rotating coil. The idea proposed eliminates the brush and commutator arrangements by performing the commutation through one of the existing support bearings in ends of the shaft and an auxiliary bearing. By changing the bearing design, commutation can be achieved by the virtue of rotation just like the brushed model.

Design changes are done to the pair of bearings that perform the commutation on the non-driven side of the bearings. Alternate rolling balls of each bearing is removed thereby creating a bearing with half the rolling balls. But since the alternate balls are removed and the two bearings are maintained at their respective positions, this doesn’t create any stability issues with the construction. There is a common inner



ring for both the bearings. The inner ring of the bearings is cut into sections of conducting strips with insulations dividing the outer surface of inner ring into segments of conducting sections. The number of poles in the rotor decides the length of each segment. The corresponding segments are connected to the armature winding, similar to the commutator in the conventional machines. Unidirectional voltage is supplied to the outer ring of the bearings, creating a closed circuit with the armature winding and the field depending on the configuration. The rolling balls perform the conduction, serving as the sole contributors for the commutation. The rolling balls are made of materials will high electrical conductivity and low thermal conductivity. Conductive lubricants are used.

The major components of a deep groove ball bearing are the outer and the inner rings, the metal balls and separators for support.

The outer ring of the bearing connects the component to the static part, in case of the DC machine. Design changes to accommodate a conducting and an insulating material in the outer ring is done. The outer ring is divided into two layer, the outermost cover and inner conductor. The outer cover is made up of an insulating material to prevent the leakage of current through to the outside of the bearing.

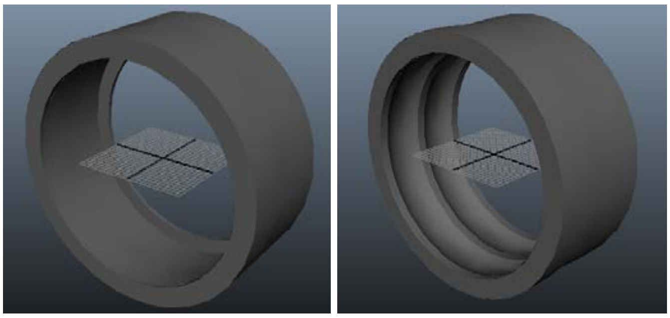


Fig. 5. The Outer Ring

The outer cover has a covering groove on the side to prevent the leakage of the current from the sides. This accommodates the inner conductors also and prevents them from slipping off the sides. The inner conductor is a ring of metal which is designed to stay in the groove of the outer cover. The design of the inner face of the conductor is done to support two tracks. Both tracks have a curvature so as to accommodate the balls rolling on the track. Generally the arc of curvature of the track is twice the diameter of the balls. Might not apply in all the cases. The conductors are a continuous strip of metal with high electrical conductivity and low thermal conductivity. This is done to ensure that the resulting heat from current exchange is prevented from being transferred through the bearing to the external environment. The outer ring in this design, gets power from the external circuit and transfers it to the rotor of the machine. Although it doesn't directly conduct power to the rotor, it is the first point of contact of the commutation system to the external power circuit. The inner ring of the design is the important modification that aids in commutation. The Inner ring of the bearing is divided into two layers similar to the outer ring. The outer cover and the conductors. The outer cover is made of insulating material, which prevents the leakage of current from the bearing. It has chambers which accommodate the segments of the conductors from the inner surface. The chambers are shown in the figure. The conductor segments are placed inside the chambers and fixed. The walls of each chamber splits the conductor segments from each other. This is an important modification in the bearing design, which provides the action of commutation during the virtue of rotation.

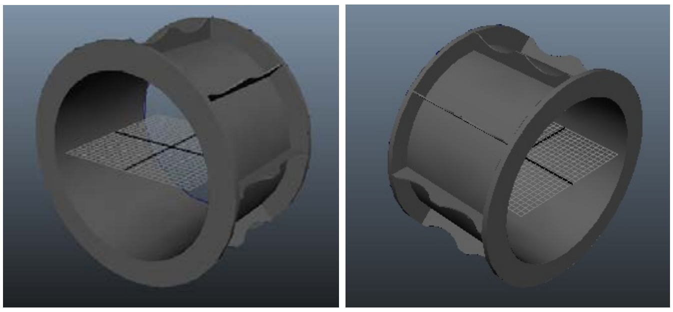


Fig. 6. The Inner Ring

It is to be noted that the outer cover as shown in the figure is a non-conducting material so as to prevent leakage current. The upper wall of the chamber is cut in the shape of the conductors to provide a smooth track on the inner side of the inner ring for the balls to revolve around them. The conductors of the inner ring are placed in between the chambers of the outer cover. The conductors are segments of strips of metals which serve as a suplier of current to the rotor. This is the exit point of the current from the whole bearing assembly.

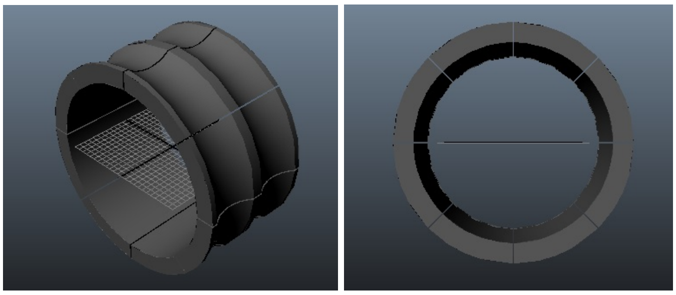


Fig. 7. Conductors of the Inner Ring

The conductor segments are designed with a curvature in order for the ease of the balls in the bearing to rotate and to prevent the balls from sliding out of the bearing. The segments are separated from each other by the chamber walls of the outer cover, which are insulators and thereby isolating each segment from each other. The conductors are made up of material with high electrical conductivity and low thermal conductivity. The inner ring rotates along with the rotor and it is directly connected to the rotor windings.

Rolling balls are the moving part of the bearings. The balls revolve around the inner ring of the machine. In motors, the inner ring is driven by the current transferred from the balls and in turn, the rings rotate and rotate the balls. The balls are metallic spheres which rotate transfer electrical current from the outer ring to the inner ring. When the inner ring rotates, it rotates the balls to the same circumference, which in turn, the balls rotate on the circumference of the outer ring. When a ball rolls over a segment, the direction of the current changes and hence reverses the current direction to the armature winding. Thus the commutation in the winding is achieved.

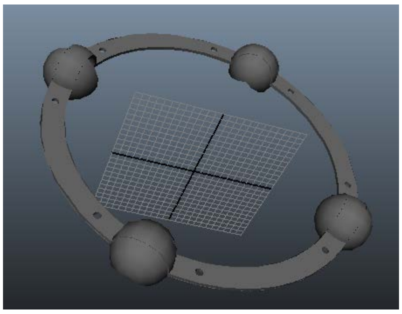


Fig. 8. Balls with the Support Holder

There are two tracks in the bearing in which balls are placed in the alternate segments. The balls are equally distributed on either of the tracks with each ball on each segment. The outer ring of each track is connected to the external supply. When the rotor starts to rotate, the segments act like the commutators and aid in the reversal of the current in the machine.

V. DYNAMIC COMMUTATION

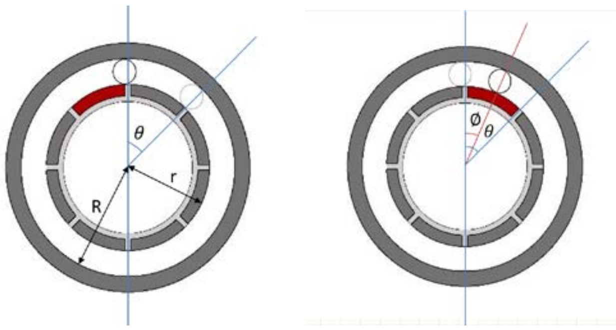


Fig. 9. Dynamic Commutation

Unlike a static brush, the balls tend to rotate around the inner ring, and hence the angle of commutation also changes accordingly to the position of the balls. Length of the arc is given by the Eqn. (1.1).

$$\frac{2\pi r}{360}\theta = \frac{2\pi R}{360}\emptyset \qquad \dots (1.1)$$

So from the above Eqn. (1.1), it is clear that, by changing the diameter of the ball, the angle of commutation can be modified. This is also directly related to the number of poles in the machine.

VI. Design Results

Performance characteristics of the modificed design with the existing design are compared. Fig. 10 shows the Efficiency vs Armature current plot and the Speed vs Armature current plot. The difference between the reference and modified versions are shown.

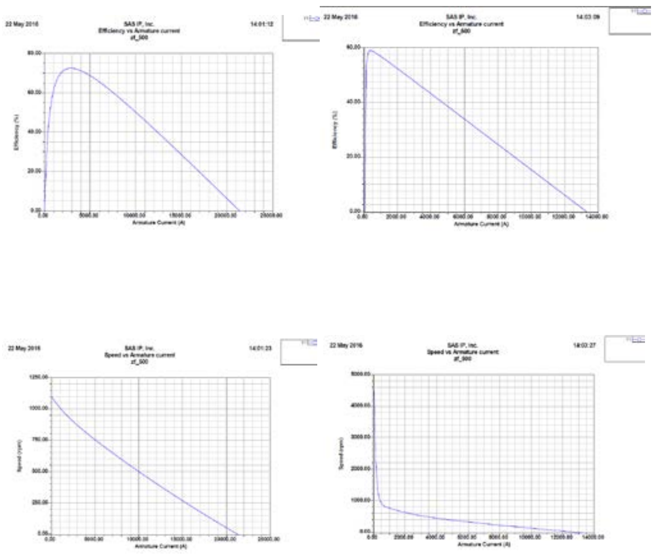


Fig. 10. Performance characteristics

VII. Conclusion

Hence from the results it is clear that the proposed design can only be used for low power short duration applications which require higher starting torque. The design can be adopted to applications like the window controller in automotive application. Hence further analysis is required on the proposed design from a mechanical perspective for its stability and robustness. The identified shortcomings need to be addressed by improving relevant areas. Further, other shortcomings and limitations need to be identified and new adaptations or modifications can be done to make its performance characteristics better. The positive aspects identified need to be made consistent with the further modifications done. This project work provides an overview of the design changes proposed. Further data can be obtained by creating a prototype and performing extensive tests to analyze and compare its characteristics with the existing design.

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