Enhancement of Combat Effectiveness by BLDC Motor in Armoured Fighting Vehicles

C. Jaishankar
Scientist 'E',
Combat Vehicles Res & Dev Establishment
Defence Res. & Dev. Organisation,
Avadi, Chennai, India

R. Prabhavathy
Scientist 'G',
Combat Vehicles Res & Dev Establishment
Defence Res. & Dev. Organisation,
Avadi, Chennai, India

***Abstract*— This paper describes the development of reliable, compact light weight BLDC motor for Armoured Fighting Vehicle (AFV) applications. Comparative study has been carried out with the existing conventional wound type DC motor and the results are presented**

***Keywords*—BLDC, AFV, rare earth magnets**

I. INTRODUCTION

Any application requiring an electric motor, where the space and weight are premium, BLDC motor is the first choice. The reliability of PMDC motor reduces at high speed because of the commutating brushes. The BLDC motor with high energy permanent magnets like Neodymium Iron Boron(NdFeB) or Samarium Cobalt (SmCo) is ideal for reliable and maintenance free operation.. A BLDC motor has high power to mass ratio, good dissipation characteristics and high speed capabilities. In view of these advantages, BLDC motors are replacing its counterpart vis-a-vis brush type DC motor in defence application and aero space applications. The applications includes fuel pumps, brake motors, servo motors and lot more.

In a Armored Fighting Vehicle (AFV) where the enclosure is made-up of steel , cooling fans are the only way of giving comfort to the crew by means of circulating the air. Normally each crew will be having one fan and the fan will be always running. The requirements of the fan are as follows

- Reliable
- Long life
- Maintenance free
- Efficient

In the present scenario, conventional wound type DC motors are used for the fan application. The operation is noisy, needs periodical check on brushes and limited life. Hence there is a requirement to go for a BLDC motor to replace the conventional motor DC motor.

II. BLDC MOTOR

A compact, light weight BLDC motor with integrated controller is developed to replace the conventional motor. The motor has been tested as per MIL-STD 810 F and comparative study has been carried out with respect to the existing conventional DC motor.

The construction of BLDC motor is similar to ac permanent magnet synchronous motor. The main difference between these motors is that BLDC motors must be provided with sensors to detect the rotor position. The signals from the sensors are used to turn the stator phases on or off, at specific rotor positions. The stator is similar to the stator of a poly phase induction motor. The rotor is a permanent magnet assembly generating radial flux fields that interact with the stator winding field. During rotation, the shaft position sensor drives the electronics to maintain the stator field near its optimum position for developing torque. Because there are no windings on the rotor, size can be reduced for low inertia and faster dynamic response.

III. BASIC DESIGN CHOICES

Before a brushless motor design can begin, several important decisions must be made. The number of phases, the number of poles, the number of slots and the winding configuration must be selected. The rotor permanent magnet configuration is designed, then the stator windings are determined. The method of commutation is also an important issue which should be considered making the basic decisions about the design. Apart from the motor design there are several other environmental and performance requirements that must be taken into account.

A. Number of Stator Slots & Poles

The choice of the number of poles depends upon many factors, some of which are as follows

1. Magnet material and grade
2. Rotor configuration
3. Mechanical assembly of the rotor and magnets
4. Speed of rotation
5. Inertia requirements

The number of poles should be inversely proportional to the maximum speed of rotation. The reason of this is to limit the commutation frequency to avoid excessive switching losses in

the transistors and iron losses in the stator. To produce higher torque and to make the end turn length smaller, the winding pitch should be minimal, which implies larger number of poles on the rotor. For the present case the number of poles chosen is eight. There is a relation between number of poles and number of stator slots and it will be decided based on many factors and the most important one is the cogging, presence of cogging torque will results in audible noise. For the fractional number of slot/pole combination the cogging torque will be minimum and the most popular combination is the 1 slot/pole/phase. In this case to reduce the cogging, to ensure noise free operation, number of slots has been chosen as 15 and this also results in lesser armature winding resistance and smaller stator back iron thickness.

B. Armature Winding Design

Double layer lap windings are used for high rating machine and requires hand insertion. Single layer windings are most suitable for automatic insertion. For this case, double layer, fractional pitch, 3ϕ Y Connected windings are selected. The windings are insulated to class F (155°C). Hall sensors mounted on PCB is used for rotor position sensing and in-turn generate pulses for commutation. Armature is made up of laminated silicon steel(M19).

C. Mechanical sizing

The mechanical dimension for any design is the most important task. For radial flux motors

$$T = kD^2L \tag{1}$$

Where

T – torque N-m

D – the rotor dia in m

L – axial length in m

k – constant

D. Mechanical Design

The motor is fully enclosed with surface cooling. For silent running, deep groove ball bearings are chosen. The stator and rotor assemblies are mounted with very high strength adhesive.

E. Magnetic Materials

The rotor has rare earth permanent magnets on its outer periphery. The magnetic material that has been used in many applications is neodymium iron boron. These magnets can obtain higher performance but the NdFeB material has significant thermal limitations. The reversible temperature coefficient is about 0.1% compared to 0.025% for samarium cobalt. The permanent degradation can occurs at 150°C, while samarium cobalt (Sm2Co17) magnet can withstand temperatures of 300° to 350°C without damage. NdFeB rotor magnets lose magnetic energy with increasing temperature. Though there has been tremendous improvements in the NdFeB magnets, because of the proven quality Sm2Co17 magnet is selected for this application. Table.1 provides data for two of the more common magnetic material.

TABLE I. PROPERTIES OF MAGNETS USED

Parameter	NdFeB	Sm2Co17
Remanence (Br) T	1.6	1.2
Coercivity (bHc) kA/m	950	800
Energy density(BH)max kJ.m3	350	250
Reversible teperature coefficient % K	-0.12	-0.045

Because of the excellent thermal characteristics samarium cobalt material is chosen for our application.

TABLE II. MAIN CONSTRUCTIONAL FEATURES

PART	PMBLDC
Stator	Punched lamination
Rotor	Solid hub
Stator winding	Insulated copper wire

TABLE III. MATERIAL DATA

PART	Material
Stator lamination	Silicon Iron
Rotor Magnet	Samarium Cobalt
Impregnation material	Varnish (Class F)
Adhesives	Araldite / Loctite
Motor & Sensor lead wire	Insulated silver plated conductor
Slot liner	3 M epoxy coating

TABLE IV. PHYSICAL DATA OF THE MOTOR SYSTEM

Parameter	Value
Number of phase	3
Number of poles	8
Number of slots	15
Slot depth	11mm
Winding	Double layer
Coil span	1 -2
Coils/phase	5
Winding connection	star
Magnet thickness	2.25 mm

FEM analysis has been carried out for optimum magnetic cicuit design and also to ensure that the magnetic circuit saturation is avoided. The results show that magnetic flux density is within the design limits and the plot is shown along with stator in Fig.1a and the air gap flux density is shown in Fig.1(b).

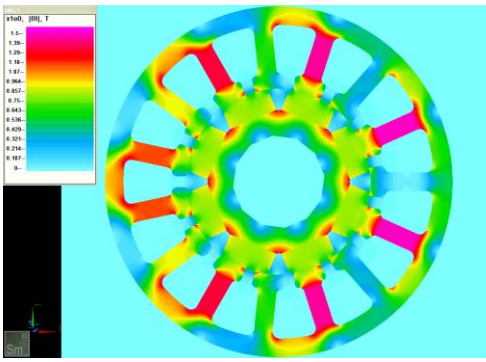

Fig.1a Flux Density Plot-FEM analysis result

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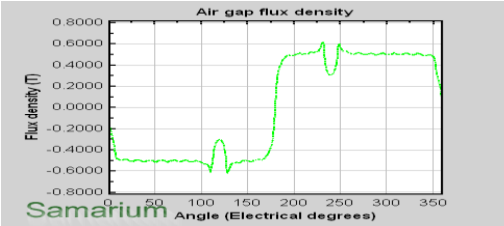

Fig.1b Air gap Flux Density

F. *Rotor Position Sensing*

Rotor position sensing of BLDC motor is done by

1. Hall elements
2. Optical or absolute encoders
3. Back emf
4. Search coils

Fig. 1. Stator

Hall PCB

G. *BLDC Controllers*

Many BLDC motor controllers use hall effect inputs with or without the power devices integrated. The hall effect sensors can be connected directly on the motor or a small circuit may be required. Recently methods using the back emf voltage sensing have been used. This mode of operation is referred to as sensor-less commutation because the need for hall effect sensors is eliminated. There are some controllers having both the mode of operation and it is the designer choice to select the right one depending upon the application.

In the present case, the controller is built around L 6235 controller which includes all the circuitry needed to drive a three phase BLDC motor and the hall sensors are mounted on a separate PCB and the position of the hall sensor is fixed for optimum commutation. The controller is mounted in the same housing of the motor thus ensuring a single assembly.

IV. TESTING

A complete program of design, development and production should have three test phases. These are development, qualification and acceptance testing. Specific test requirements and specifications are program dependent, so formal documentation must be defined in the product specifications.

A. *Development Testing*

Development testing should be performed to ensure acceptable performance and search for design flaws. The test motor should be as close as possible to the final units. Several development tests were performed as listed below. Some of these are needed for unit characterization only, others should provide an early indication of the ability to pass qualification testing.

1. Rated load test - 72 hrs
2. Temperature rise test
3. Stall test

B. *Qualification Testing*

A formal qualification test has been carried out as per MIL-STD 810 F to check for design problems over the total operating and non-operating conditions. As a minimum the following tests were carried out

1. Performance test
2. Insulation test
3. Temperature rise
4. Vibration test
5. High temperature operation and storage and operational
6. Low temperature storage and operational
7. Rapid temperature cycling
8. shock test
9. Salt corrosion test
10. Mould growth test
11. EMI/EMC tests as per MIL-STD 461E

C. *Acceptance Testing*

The purpose of acceptance testing is to assure that manufacturing variation do not result in out of tolerance performance. The acceptance testing is configured to identify defects related to manufacture and not design.

The following tests are the minimum necessary to assure a reliable unit.

1. Raw Material Inspection
2. Dimensional Inspection
3. Functional check at sub-assembly level
4. Functional check at unit level
5. Insulation test
6. Di-electric strength

D. *Comparative study*

In the Armored Fighting Vehicle(AFV), there are four crew cooling fans driven by conventional wound type DC series motor located in different compartment. The fan motor is fitted with rubber blades on its rotor shaft and delivering air at the velocity of 5 m/s . The fan blades are made up of chloroprene rubber, so by accidental physical contact by the crew will not cause any harm to the crew. These fan motors are operated at a nominal 28 V DC supply.

The BLDC motor with integrated controller is configured in such a way that there will not be any changes in the existing harness of the tanks. And the mounting stand and the blade assemblies are same as the existing fan assembly. Hence there is no change in mounting arrangements and harness. After the development of the motor, the motor has passed all the tests which are mandatary and integrated in the AFV, replacing the existing motor. Tests were conducted and the comparative test results are shown in the following Table.V

TABLE.V - Comparison of test results

Parameters	Existing conventional motor	BLDC motor
Stall Protection	Not available	Provided
Current (A)	0.8	0.4
Speed (rpm)	2700	2700
Weight (gm)	675	360

It is very clearly understood from the test results, the BLDC motor consumes 50 % less power than existing brush type motors. For the same air delivery the conventional motors draw 0.8 - 0.9 A current where as the BLDC motor draws only 0.4 A. There is a reduction of 40 – 50 % in the weight of the BLDC motor in comparison with its counterpart which results in 300 grams (approximately) of weight reduction in the overall fan assembly.

The reduction in the power requirement of BLDC motor increases the life of the battery and which in turn aids the combat effectiveness during silent watch mode of operation. In comparison with the conventional motor, the energy drawn from the batteries is half which enhances the operational availability of the battery to a great extent or the power can be used for operating other equipment and thus improving the combat effectiveness of the AFV.

BLDC Motor Existing wound field DC motor

V. CONCLUSION

In this paper, development of a 8 pole BLDC motor with samarium cobalt magnet (Sm2Co17) for AFV application is described. Established design methods for BLDC motor were used to design the motor . Special considerations were given to reduce cogging torque. Necessary QT & AT tests were carried out to ensure the reliable operation of the system. Prototype motor has been developed and qualified for AFV application and performance is found satisfactory during field trial. The influence of BLDC motor on the energy saving aspects also discussed for improving the combat effectiveness. Owing to high reliability, fit and forget nature these BLDC motors will replace conventional motor in future in all application.

It is concluded that the replacement of the existing brush type motors with brushless motors offer 50 % saving in power consumption, reduction in over all fan assy. weight and volume by 40 % , enhanced useful life period which requires no maintenance and ensures trouble free and reliable operation.

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